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(54) **Method of producing a train running plan**
Verfahren zum Erzeugen eines Zuglaufplanes
Méthode de production d'un plan de roulage pour train

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Description

BACKGROUND OF THE INVENTION

The present invention relates to a method of producing a train running plan which is effective for realizing a high speed, high density, and energy-saving running of a railway train.

With respect to a method of producing the optimal train running plan under the conditions such as line conditions, e.g., a limit speed and a grade, and rolling stock characteristics, e.g., a running resistance, driving force characteristics, and speed decreasing characteristics, there are published the following literatures:

Literature 1;	5th National Symposium for Utilization of Cybernetics in a Railway, June, 1968, pp. 11-16; and
Literature 2;	The Transactions of the Institute of Electrical Engineering Engineer's of Japan, Vol. 106-B, No. 9, September, 1986, pp. 769-776.

The method in the literature 1 is such that the optimal running method is obtained in the running of arbitrary form between stations on the basis of the dynamic planning by treating the running time, the power consumption and the number of notch switching as the objective factors. This method is obtained in the form of notch sequence. Then, the running time, the power consumption and the like as the objective factors are obtained by performing the running simulation of the train to determine the position, the speed and the like of the train.

In the literature 2, the discussion is made with respect to the energy-saving running method in the running of the super-express railway's train stopping every station, between the stations. In the literature 1, the calculation is made by the simulation with the time base being divided since the equation of motion of the train cannot be exactly obtained in the large area. On the other hand, in the literature 2, each of the strict solutions is obtained on the assumption that the magnitude of the grade takes a fixed value and the resultant solutions are linked to one another to perform the calculation of the consumed energy, the necessary time and the like.

The discussion about the energy-saving running method in the literature 2 is made in such a way that four patterns near the actual running are prepared, the consumed energy is calculated every running pattern on the assumption that the magnitude of the grade is zero over the whole territories, and the predetermined comparison is performed. Out of the four running patterns, the running pattern having the minimum consumed energy provides the results of the maximum acceleration → the fixed running at the maximum speed → stopping by the repetition of the coasting and the normal maximum braking.

In the above-mentioned running pattern having the minimum consumed energy, only the maximum speed is changed to obtain the speed in which the necessary time coincides with the schedule time for realizing the scheduled running in which the necessary time coincides with the schedule time.

However, in the prior art method of obtaining the optimal running plan on the basis of the dynamic planning in the literature 1, there arises a problem in that the calculation requires much time.

In the literature 2, as the running pattern of the limit speed between the stations, only the pattern shown in Fig. 1 is supposed. Thus, the method described therein can be applied to only this running pattern. Therefore, it cannot be applied to the complicated pattern as shown in Fig. 2 for example.

Further, in addition to the literatures 1 and 2, with respect to the method of changing the train running plan produced in advance in the train in a real-time manner, there is published the literature 3, i.e., The Transactions of the Institute of Electrical Engineering Engineer's of Japan, Vol. 107-D, No. 5, May, 1987, pp. 665-672.

The method described in the literature 3 is about the running plan of the super-express railway's train stopping every station. In this case, the running pattern as shown in Fig. 1 is supposed as the running pattern of the limit speed. Then, out of a plurality of running methods which are supposed in advance, one providing the minimum energy-saving is determined on the assumption that the magnitude of the grade is zero over the territory shown in Fig. 1. The resultant energy-saving running method is such that the running pattern is obtained by combining the maximum acceleration, the fixed speed running, the coasting and the maximum deceleration with one another.

In the running method having such a running pattern, the parameters which are to be determined in advance are the maximum speed and the deceleration starting point in the running territory. The two parameters are changed so as to provide the maximum energy-saving running under the condition of the scheduled running (the running time coincides with the schedule time).

In the method described in the literature 3, only the running pattern as shown in Fig. 1 is supposed as the running pattern of the limit speed between the stations, the method of energy-saving running is determined in advance, and only the determination of th deceleration starting point is performed in the real-time chang in the train. Therefore, this method cannot cope with the occurrence of change of the limit speed as shown in Fig. 3A, for example, which is not supposed in advance.

SUMMARY OF THE INVENTION

It is th object of the present invention to determine the target speed so as t provide the minimum consumed energy during the running of the train.

This object is met by a method according to claim 1. Preferred embodiments are disclosed in the depending claims.

The general pattern of the limit speed between the stations is supposed as shown in Fig. 4, and the running patt rn on the basis of that limit speed is assumed here. Then, the limit speed territories in Fig. 4 are numbered serially (the number of territories is N). At the same time, it is assumed that the limit speed in the I-th limit speed territory is $V_{MAX,i}$ and the running speed to be targeted (hereinafter, referred to as simply "the target speed", when applicable) is Vi. Then, the relationship of $Vi \leq V_{MAX,i}$ is established.

Under such assumptions, to set the target speed (it is not always possible to reach this target speed) every limit speed territory is determined the train running method between the associated stations. For example, in the running pattern of the maximum acceleration → the fixed speed running → the deceleration by the normal maximum braking, under the limit speed of $V_{MAX,i}$ (i=1, ..., N), if Vi (i=1, ..., N) is established, the train running method between the associated stations is correspondingly established. Conversely, it is also true that to establish the train running method between the stations is to establish Vi (i=1, ..., N).

By the optimal running method in the train running method as described above, it means the scheduled running in which the necessary time required for the train to run between the stations coincides with the schedule time and at this time, the minimum consumed energy is obtained.

It is assumed that the necessary time required for the train to run through a predetermined territory is T and the consumed energy is E. Then, the necessary time T and the consumed energy E cannot be analytically calculated even if the line conditions and the rolling stock characteristics as already described are known. However, these factors can be obtained by making the equation of motion of the train discrete corresponding to the travel distance and by performing the numerical calculation (i.e., by performing the simulation).

At this time, if Vi (i=1, ..., N) is established, the necessary time T and the consumed energy E are uniquely obtained. Therefore, each of T and E is a function of Vi (i=1, ..., N). That is, the following relational expressions are established:

$$T = T(V_1, ..., V_N), \ E = E(V_1, ..., V_N) \qquad (1)$$

Then, to obtain the optimal Vi (i=1, ..., N) is established mathematically in such a way as to obtain a set of target speeds $V_1, ..., V_N$ for minimizing the objective function $E(V_1, ..., V_N)$, under the condition of the necessary time $T(V_1, ..., V_N)$ = the schedule time T_D.

More specifically, Vi is changed so as to decrease the consumed energy E, and for example, the partial derivative $\partial E/\partial Vi$ of E with respect to Vi is obtained. Thus, the direction of decreasing of E is obtained. There is known a non-linear planning in which the calculation for obtaining the direction of decreasing of E is repeated until the necessary time T approaches the scheduled time T_D within the range of a certain allowable error δT, and when the necessary time T becomes in the range of the allowable error, the above calculation is finished.

Or, the following equation may be used as the objective function.

$$J = E + \alpha\{(T - T_D)/\delta T\} \qquad (2)$$

In this case, it is possible to simultaneously evaluate both the consumed energy E and the necessary time T. At this time, the evaluation by only the consumed energy E can be performed in the case of $\alpha = 0$.

The above description has been given with respect to the specific case where the train runs through the territory between the two stations, and it is then stopped at the following station. However, even in the case where both the two stations are passed stations, the same means can be used by giving the initial speed at the first station in addition to the above conditions.

When the running speed of the train is changed, the subsequent target speed $\underline{V} = (V_1, V_2, ..., V_N)$ as a vector form is newly obtained on the basis of the change ratio of the consumed energy between that running speed and the target speed of interest. Therefore, the component of the gradient vector $\nabla E(\underline{V})$ in the direction of decreasing of the consumed energy E is obtained from the following approximate expression.

$$\partial E/\partial V(n) \fallingdotseq \Delta E/\Delta V(n) \qquad (3)$$

That is, th target speed V(n) is changed in the direction of th gradient vector, and th target speed V(n) for minimizing the consumed energy E is obtained.

According to another embodiment of th present invention, instead of the gradient vector $\nabla E(\underline{V})$, the ratio of th decreasing of the consumed energy E to the increasing of the running time T when V(n) is changed by $\Delta V(n)$, i.e., the ratio of ΔE to ΔT is used. Then, each of the components of each of the gradient vectors is obtained from the following

equation.

$$-\Delta E/\Delta T = -\{\Delta E/\Delta V(n)\}/\{\Delta T/\Delta V(n)\} \fallingdotseq -\{\partial E/\partial V(n)\}/\{\partial T/\partial V(n)\} \quad (4)$$

The value of the equation (4) is called $\rho(m)$. Then, let $\rho(n)$ be replaced with $\underline{\rho}$ as the form of vector. Then, the target speed $\underline{V}$ is changed in the direction of $\underline{\rho}$. In this case, it is assumed that the initial value of the target speed V(n) is expressed by {the limit speed Vmax(n) - (the marginal speed)}. Then, by the marginal speed it means the upper limit speed that does not exceed the limit speed during the running at the fixed speed.

In the calculation of the running time, in addition to the running curve on the speed curve which is expressed by the speed on the axis of ordinate with respect to the position on the axis of abscissa as shown in Fig. 5, the curve of the inverse number of the speed is also utilized. Since the single integral of the inverse number of the speed with respect to the position on the axis of abscissa becomes the running time of the territory of interest, it is herein referred to as "the running time density", and is expressed by λ.

The characteristics of the train are characterized by the acceleration and deceleration characteristics, the running resistance and the like. With the train, it is assumed that all the grades of the traffic line are zero. Then, as shown in Fig. 7, in the acceleration up to the suitable speed more than the maximum speed on the line, the data about the running speed v, the running time density λ and the running time T with respect to the running distance x are produced. Now, the running speed v, the running time density λ and the running time T are expressed by the following equations, respectively.

$$v = p(x) \quad (5)$$

$$\lambda = 1/p(x) = f(x) \quad (6)$$

$$T = \int_0^x f(\zeta)d\zeta = F(x) \quad (7)$$

Moreover, as shown in Fig. 8, the individual data in the deceleration from the running speed $\underline{v}$ of interest are also produced. In this case, the running speed v, the running time density λ and the running time T are expressed by the following equations, respectively.

$$v = q(x) \quad (8)$$

$$\lambda = 1/q(x) = g(x) \quad (9)$$

$$T = \int_0^x g(\zeta)d\zeta = G(x) \quad (10)$$

Since each of the functions p(x), q(x), f(x), g(x), F(x) and G(x) is a monotonous function, these functions have respective inverse functions. Moreover, as the functions necessary for the calculation of the running time, the data of $F(f^{-1}(\lambda))$ with respect to the variable λ in the acceleration and the data of $G(g^{-1}(\lambda))$ with respect to the variable λ in the deceleration are produced.

Although these functions are not always clearly expressed in the form of formula, they are stored in the computer in the form of discrete numeral data.

Fig. 9 is a graphical representation showing the running of the train in which the fixed speed running is performed up to the position x_1 at the speed V_1, the acceleration is started from the position x_1, the running speed reaches the speed V_2 in the position ξ_1, the fixed speed running is performed up to the position x_2 at the speed V_2, the deceleration is started from the position x_2, the running speed reaches the speed V_3 in the position ξ_2, and the fixed speed running is performed up to the position x_3. Incidentally, in this case, it is also assumed that the magnitude of the grade is zero in each of the running territories.

Moreover, Fig. 10 is a graphical representation showing the inverse number of the speed, i.e., the running time density. The running time density is expressed by the following equation.

$$\lambda i = 1/Vi \ (i=1, 2, 3) \quad (11)$$

The position ξ_1 where the running is switched over from the acceleration to the fixed speed running can be obtained using the speed curve p(x) in the acceleration of Fig. 7, and the distance required for the acceleration from V_1 to V_2 can be obtained by the following equation.

$$p^{-1}(V_2) - p^{-1}(V_1) = \xi_1 - x_1 \tag{12}$$

The running time T_A from x_1 to ξ_1 corresponds to the area A shown in Fig. 10. In order to obtain this running time T_A, the travel territory between x_1 and ξ_2 is converted into the characteristics shown in Fig. 7 and the resultant characteristic curve of Fig. 7 is then integrated. First, the positions y_1 and y_2 corresponding to λ_1 and λ_2 are given by $y_1 = f^{-1}(\lambda_1)$ and $y_2 = f^{-1}(\lambda_2)$, respectively. Therefore, the running time T_A is given by:

$$\begin{aligned} T_A &= \int_{y_1}^{y_2} f(\zeta)d\zeta = \int_{f^{-1}(\lambda_1)}^{f^{-1}(\lambda_2)} f(\zeta)d\zeta \\ &= F(f^{-1}(\lambda_2)) - F(f^{-1}(\lambda_1)) \end{aligned} \tag{13}$$

Moreover, the running time T_B from ξ_1 to x_2 corresponds to the area B and is given by $\lambda_2 \cdot (x_2 - \xi_1)$. As a result, the running time T_{AB} from x_1 to x_2 is obtained using the following equation.

$$T_{AB} = F(f^{-1}(\lambda_2)) - F(f^{-1}(\lambda_1)) + \lambda_2 \cdot (x_2 - \xi_1) \tag{14}$$

The position ξ_2 where the running is switched over from the deceleration to the fixed speed running is obtained from the following equation, using the speed curve q(x) in the deceleration of Fig. 8.

$$q^{-1}(V_3) - q^{-1}(V_2) = \xi_2 - x_2 \tag{15}$$

In the same manner as in the acceleration, the running time Tc from x_2 to ξ_2 is given by:

$$\begin{aligned} T_c &= \int_{g^{-1}(\lambda_2)}^{g^{-1}(\lambda_3)} g(\zeta)d\zeta \\ &= G(g^{-1}(\lambda_3)) - G(g^{-1}(\lambda_2)) \end{aligned} \tag{16}$$

The running time T_D from ξ_2 to x_3 corresponds to the area D and is given by $\lambda_3 \cdot (x_3 - \xi_2)$. As a result, the running time T_{CD} from x_2 to x_3 is obtained using the following equation.

$$T_{CD} = G(g^{-1}(\lambda_3)) - G(g^{-1}(\lambda_2)) + \lambda_3 \cdot (x_3 - \xi_2) \tag{17}$$

The reason for performing the calculation on the assumption that the magnitude of the grade is zero in the above description is that since the magnitude of the grade depends on the place, taking the actual grades into consideration, it is impossible to produce the desired data in advance by the simulation. However, the following items are true:

1. Since the recalculation of the running time in the train is necessary for the territory where the change of the limit speed occurs locally and the subsequent several territories, the distance requiring the recalculation is short. Thus, there is a small error between this case and the case where the magnitude of the grade is taken into consideration.
2. Such a territory where the change of the limit speed occurs is mainly included in the high speed area, and therefore, there is small influence of some variation of the speed due to the grade upon the running time.

For the above reasons, there is the small error between the present case and the case where the magnitude of th grade is taken into consideration.

As described above, the necessary data are calculated in advance by th simulation and th like, and the running time is then calculated using the resultant data, whereby it is possibl to correct the running method which is set in advance, in a real-time manner.

According to the present invention, the necessary data is calculated in advance by the simulation Even when the necessity of correcting the train running method occurs, e.g., the chang of the limit speed temporarily occurs, it is pos-

sible to correct the running method in the train in a real-time manner.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a graphical representation showing a prior art running pattern of a limit speed between stations;
Fig. 2 is a graphical representation showing an example of a running pattern of a limit speed between stations;
Fig. 3A is a graphical representation showing an example of the running pattern in the case where the setting of the limit speed occurs temporarily;
Fig. 3B is a graphical representation showing an example of the running pattern corresponding to the inverse number of the limit speed illustrated in Fig. 3A;
Fig. 4 is a graphical representation showing an example of the running pattern of the limit speed between the stations;
Fig. 5 is a graphical representation showing a running pattern used for correcting the running plan;
Fig. 6 is a graphical representation showing the inverse number of the running pattern shown in Fig. 5;
Fig. 7 is a graphical representation showing the speed, the inverse number of the speed and the running time in the acceleration in the case where the magnitude of the grade of the travel territory is "0";
Fig. 8 is a graphical representation showing the speed, the inverse number of the speed and the running time in the deceleration in the case where the magnitude of the grade of the travel territory is "0";
Fig. 9 and Fig. 10 are graphical representations useful in explaining the calculation of the running time using the inverse number of the speed;
Fig. 11 is a block diagram showing the arrangement of a system for carrying out a method of producing a train running plan according to the present invention;
Fig. 12 is a flow chart showing the method of producing a train running plan of a first embodiment according to the present invention;
Fig. 13 is a diagram useful in explaining an example of the running plan which is displayed on a CRT of a train system;
Fig. 14 is a graphical representation showing an example of the grade data of a limit speed territory;
Fig. 15 is a graphical representation showing the running pattern of the limit speed which is used when a train passes a station;
Fig. 16 is a flow chart showing the method of producing a train running plan of a second embodiment according to the present invention;
Fig. 17 is a flow chart showing the method of correcting a train running plan;
Fig. 18 and Fig. 19 are graphical representations useful in explaining examples of correction of the running plan; and
Fig. 20 and Fig. 21 are graphical representations useful in explaining another examples of correction of the running plan.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Preferred embodiments of the present invention will hereinafter be described in detail with reference to the accompanying drawings.

Fig. 11 is a block diagram showing the arrangement of a system for carrying out a method of producing a train running plan according to the present invention.

This system arrangement is made up of a train system 200a having a main function of displaying an optimal train running plan on a CRT 203 provided in a train to perform the operational support for an engineer, and a ground system 200b having a main function of producing the optimal train running plan to be displayed by the train system 200a.

Moreover, for brevity, it is assumed that the traffic route is a line consisting of two rails, a plurality of stations are included in the traffic route, a running train is limited in type, and each of the trains is a local train.

A running plan producing unit 208 serves to refer to the necessary data in a rolling stock characteristic data file 212 and a line condition data file 213 to produce optimal train running plan thereby to store the optimal train running plan in a running plan data file 211. This processing is performed in advance with respect to all the territories, the type of the train, the up train line and the down train line.

Then, to determine the train plan is to determine a target speed in each of the limit speed territories. Incidentally, in addition to the target speed, the curve of the speed corresponding to the position on the line, which is designated the running curve, will be also displayed in the train. In th data file 211, the result of the simulation when the optimal target speed is set will be recorded in the form of the position and the speed. The details of the method of producing an optimal train running plan will be described later with reference to Fig. 12.

Then, by the rolling stock characteristic data it means the drive force characteristic data and the deceleration characteristic data corresponding t the train speed, the running resistance which is a function of the second order of the

train speed, the train organization, the train weight and th like all of which are inherent in the train. These rolling stock characteristic data are stored corresponding to the type of the running train.

Moreover, by th lin condition data it means the position of the stati n (stopping target position), the limit speed information (territory starting position and limit speed, etc.), the grade information (starting position and magnitude f grade, etc.) and the like all of which are obtained with the starting point of the traffic route being treated as a standard. Since it is assumed that the traffic route is a single line, these data are limited to only two kinds with respect to the up train line and the down train line.

Out of the data of the optimal train running plan thus produced, the data corresponding to the running train and the territory between the stations at which the train is to be stopped in order need to be transferred to the train system 200a of the running train. As for the means for transferring such data, there are known various kinds of ones. However, particularly in the present example, an IC card is used to transfer the data from the ground system 200b to the train system 200a. The running plan producing unit 208 serves to search for the necessary data to take out them from the data fil 211, thereby to send them to an IC card writer 214. The IC card writer 214 serves to write the data thus sent thereto in an IC card 215. The IC card 215 having the data written therein is the same as an IC card 206 in the train system 200a.

A running support unit 201 serves to read out the running plan from the IC card 206 through an IC card reader 207 prior to the start of the train and to record the running plan in a running plan data file 204 in a train computer. Further, the running support unit 201 performs the display of the present position, the target speed at the present position, the running curve in the running plan, and the like on a CRT 203, corresponding to the travel position of the train. A keyboard 202 in the train system 200a and the 209 in the ground system 200b are used for the input of the commands and the like when the respective systems are operated and so forth. An example of the displayed picture is shown in Fig. 13.

In Fig. 13, the reference numeral 701 designates the limit speed, the reference numeral 702 designates the optimal target speed, and the reference numeral 703 designates the running curve which is obtained by performing the simulation of the running at the optimal target speed. The reference numeral 704 indicates the present position on the running curve. The target speed, the present speed, the present position and the running time are numerically displayed in areas 705, 706, 707 and 708, respectively.

Returning to Fig. 11, the position of the train is calculated in such a way that a rolling stock position detection unit 205 measures the rotational frequency of the wheel and the correction is performed in the place where the positions of the station and the vicinity thereof can be accurately grasped.

Fig. 12 is a flow chart in accordance with which the running plan producing unit 208 in the ground system 200b shown in Fig. 11 carries out a first embodiment of a method of producing an optimal train running plan.

The first embodiment is characterized in that the target speed is determined so as to provide the minimum consumed energy when the train is running.

In Step 101, the data inputted from the keyboard 209 is read out. The data which are inputted from the keyboard 209 are made up of the type of the train, the identifiers with respect to the individual stations, the starting time, and th estimated time of arrival.

In Step 102, on the basis of the data thus inputted, the line condition data with respect to the stations at which the running train is to be stopped in order (the line length, the station position, the limit speed information, the grade information and the like) and the rolling stock characteristic data of the running train (the drive force characteristics, th deceleration characteristics, the train weight and the like) which are stored in advance in the files 213 and 212 of the ground system 200b, respectively, are read out. The train weight is calculated on the basis of the average seat-load factor (it is estimated from the past data and the like).

In Step 103, on the basis of the above data thus read out, the target speed which is obtained by subtracting the marginal speed from the limit speed is assigned to each of the limit speed territories. The marginal speed is set so as not to exceed the limit speed during the fixed speed running. Thus, for example, if the marginal speed is set to 3 km/h, when the limit speed is 100 km/h, 97 km/h is set to the target speed.

In Step 104, the necessary time T and the consumed energy E in the case where the train will run between the stations at the target speed thus set are calculated. The concrete method of calculating the necessary time T and the consumed energy E will hereinbelow be described.

The running pattern of the limit speed shown in Fig. 4 is used as that in the present embodiment. The axis of abscissa designates the distance from the starting station and will hereinbelow be represented by x. The limit speed territories are numbered serially (the total number of territories is N). At this time, it is assumed that the starting position of the i-th territory is x_i and the limit speed thereof is $V_{MAX,i}$. That is, if the position of the train satisfies the relationship of $x_i \leqq x \leqq x_{i+1}$, the limit speed at that position is $V_{MAX,i}$.

Moreover, as described above, it is assumed that the running pattern takes the combination of the maximum acceleration → the fixed speed running → th deceleration by the normal maximum braking.

Next, it is assumed that the grade of the n-th limit speed territory is as shown in Fig. 14 and the number of territories each having the grade is Mn. Then, in th position satisfying the relationship of $\xi_{n,m-1} \leqq x \leqq \xi_{n,m}$, the grade is $\gamma_{n,m}$. Incidentally, the unit of the grade is expressed by o/oo (per mil).

The running resistance R_R is a function of th second order of the train speed v and is expressed by the following

formula:

$$R_R(v) = a + bv + cv^2 \tag{18}$$

where a, b and c are parameters inherent in the kind of the train.

The grade resistance R_G is a function of the position x. Since the unit of the grade γ is given by o/oo, if the angle corresponding to the grade is given by θ, the following relationship is established.

$$\sin\theta \fallingdotseq \theta \fallingdotseq \tan\theta = \gamma/1000$$

Thus, if the train weight is given by M, the following relationship is established.

$$R_G(x) = M \cdot g \cdot \sin\theta \fallingdotseq M \cdot g \cdot \gamma/1000$$

Then, if the drive force characteristics and the deceleration characteristics corresponding to the speed v are expressed by $T_Q(v)$ and $T_B(v)$, respectively, the equation of motion of the train motion are given by:

$$M \cdot \frac{dv}{dt} = F_M(v) - R_R(v) - R_G(x) \tag{19}$$

where $F_M(v)$ is the output of a motor ($T_Q(v)$ in the acceleration and $-T_B(v)$ in the deceleration). Since the limit speed as the constraint condition depends on the position x, the independent variable of the time t is inconvenient to treat. Then, the time t is subjected to the change of variables to obtain the independent variable x. At this time, the equation is rewritten as follows:

$$M \cdot v \cdot \frac{dv}{dx} = F_M(v) - R_R(v) - R_G(x) \tag{20}$$

Thereafter, the necessary time T and the consumed energy E can be obtained in such a way that the distance x is made to be discrete and the equation (20) is solved by the numerical calculation.

Incidentally, although it is assumed that with respect to the train running, the acceleration is performed in accordance with $T_Q(v)$ and the deceleration is performed in accordance with $T_B(v)$, the control in the fixed speed running is performed in the following manner.

The lower limit ΔVd and the upper limit ΔVu of the error between the present speed v and the target speed Vn are set. Then, the control in the fixed speed running is performed in accordance with the following relationship.

$$v \leqq Vn - \Delta Vd : \text{acceleration due to } T_Q(v)$$

$$Vn - \Delta Vd < v < Vn + \Delta Vu : \text{coasting } (F_M(v) = 0)$$

$$Vn + \Delta Vu \leqq v : \text{deceleration due to } T_B(v)$$

In order to obtain the partial derivative $\partial E/\partial Vi$ of the consumed energy E with respect to the target speed Vi, the target speed Vi is reduced by the small speed εV to perform the same calculation. If the consumed energy at this time is given by E', the following relationship is established.

$$\partial E/\partial Vi = (E - E')/\varepsilon V \tag{21}$$

Such a calculation is repeatedly performed with respect to i (i=1, ..., N).

After the completion of the above processing, with the target speed being equal to the initial setting value (i.e., in the first calculation), the schedule time (the estimated time of arrival - the starting time) is compared with the calculated necessary time (Step 105). When the schedule time is smaller than the necessary time (in the case where the train is too late for the necessary time at any high speed), it is judged that the input data are abnormal. Then, this processing is completed (Step 106). The completion of this processing is displayed on the CRT 210.

On the other hand, when the schedule time is larger than the necessary time, the difference between the schedule time and the necessary time is calculated,to compare the magnitude of the difference and the allowable error δT with each other (Step 107). If th difference therebetween is smaller than the allowable error (formation of end condition),

the target speed and the running curve data at this time are stored in the running plan data file 204 (Step 108). Thus, the processing for obtaining the optimal train running method is completed (Step 109).

If the difference therebetween is more than the allowable error δT, the processing for changing the target speed is performed (Step 110). There ar various methods for changing the target speed. For example, ther is a method in which the gradient vector having $\partial E/\partial Vi$ as the i-th component is normalized (making the length thereof 1), the length along the i-th component, i.e., that of the target speed as the vector is decreased by 5 km/h. There is another method in which the positive and maximum partial derivative is selected and the target speed is reduced by 1 km/h. In the present embodiment, the latter is employed.

Thereafter, the subsequent target speed is newly set, a series of processings beginning from Step 104 are repeated.

As another example in the method of producing a train running plan, it is supposed that the territory for providing the optimal train running plan exists between the two passed stations, as shown in Fig. 15. At this time, there is no schedule time between these stations. However, the difference between the estimated times of passing with respect to the two stations is regarded as the schedule time, the speed at passing the station at the left end (the initial speed in the simulation) is added, and the consumed energy and the necessary time are obtained by the simulation.

Thus, in the method of producing a train running plan according to the first embodiment, since the target speed in each of the limit speed territories is obtained on the basis of the nonlinear planning for obtaining the desired train running plan, the number of parameters used for determining the target speed can be decreased, and the computation time becomes less in comparison with the case of the optimal running method for all the territories by the dynamic planning or the like.

Moreover, the method of producing a train running plan of the present embodiment can be applied to the running pattern using the arbitrary limit speed.

The second embodiment of the present invention will subsequently be described. In the second embodiment, th subsequent target speed is newly obtained on the basis of the change ratio of the consumed energy with respect to the change of the running time when changing the target speed. Incidentally, as the system for carrying out the method of producing a train running plan of the second embodiment, as shown in Fig. 11 is used. Therefore, the description of the arrangement of the system is omitted here for brevity. Then, only the features of the second embodiment will hereinafter be described with reference to Fig. 16.

In Step 101a, the data of the type of the train, the identifiers with respect to the individual stations, the starting time, the estimated time of arrival, and the like are inputted from the keyboard 209.

In Step 102a, on the basis of the data inputted in Step 101a, the line condition data with respect to the stations at which the running train is to be stopped (the line length, the station position, the limit speed information, the grade information and the like) and the rolling stock characteristic data of the train of interest (the drive force characteristics, the deceleration characteristics, the train weight, and the like) which are stored in advance in the files 213 and 212 of the ground system 200b, respectively, are read out. The weight of the passengers in the train weight is calculated on the basis of the average seat-load factor (it is estimated from the past data).

In Step 103a, on the basis of the data thus read out, the initial value of the target speed of each of the limit speed territories is set by subtracting the marginal speed from the limit speed Vmax(n). The marginal speed is set so as not to exceed the limit speed during the fixed speed running at the maximum speed. Thus, for example, if the marginal speed is set to 3 km/h, when the limit speed is 100 km/h, 97 km/h is set to the target speed.

In Step 104a, the processing is performed with respect to the following two items:

(1) The simulation of the train running is performed using the target speed which is set at present to calculate the running time T and the consumed energy E. At the same time, the combination data of the target speeds at that time, and the running curve data which are expressed by the relationship between the running position and the speed are temporarily stored.

(2) The target speed of the n-th limit speed territory which is set at present is expressed by V(n). Then, the target speed of that territory is set to $V(n) - \varepsilon V$ which is obtained by reducing the target speed by the small value εV, to perform the simulation of the train running. Thus, the running time T' and the consumed energy E' are calculated. Then, the following approximate expression is calculated.

$$\rho(n) \fallingdotseq -(E - E')/(T - T') \qquad (22)$$

Such a processing is carried out with respect to n (n=1, ..., N). Incidentally, as stated in the description of the equation (4), ρ(n) represents the vector component.

Now, when the running pattern of the limit speed is that as shown in Fig. 4, the calculation method of the running time T and the consumed energy E is as follows.

The running pattern of the train is supposed in such a way that in the acceleration running, the acceleration by the

maximum accelerating force is switched over to the fixed speed running, and in the deceleration running, the deceleration by the normal maximum braking is switched over to the fixed speed running. At this time, by determining the train running plan it means that determining the target speed in each of the limit speed territories.

Then, if the drive force characteristics and th deceleration characteristics corresponding to the speed v ar expressed by Tq(v) and Tb(v), respectively, the equation of motion of the train is given by:

$$M \cdot (dv/dt) = Fm(v) - Rr(v) - Rg(x) \quad (23)$$

where Fm(v) represents the output of the motor and is expressed by Tq(v) in the acceleration while being expressed by -Tb(v) in the deceleration. Thereafter, the necessary time T and the consumed energy E can be obtained in such a way that the time t is made to be discrete and the above equation is solved by the numerical calculation.

Incidentally, although it is assumed that with respect to the train running, the acceleration running is performed in accordance with Tq(v) and the deceleration running is performed in accordance with Tb(v), the control in the fixed speed running is performed in the following manner. The lower limit ΔVl and the upper limit ΔVu of the error between the present speed v and the target speed V(n) are set. Then, the control in the fixed speed running is performed in accordance with the following relationship.

$$v \leqq V(n) - \Delta Vl : \text{acceleration due to } Tq(v)$$

$$V(n) - \Delta Vl < v < V(n) + \Delta Vu : \text{coasting } (Fm(v) = 0)$$

$$V(n) + \Delta Vu \leqq v : \text{deceleration due to } Tb(v)$$

After the completion of the above processing, in Step 105a, with the target speed being equal to the initial setting value which is set in Step 103a (i.e., in the first calculation), the schedule time (= the estimated time of arrival - the starting time) is compared with the running time which is calculated by the simulation.

By the case where the running time is larger than the schedule time, it means that in the case where the train is too late for the schedule time at any high speed. In such a case, the input data are abnormal. Then, the processing for obtaining the optimal target speed is completed (Step 106a). Then, the completion of this processing is displayed on the CRT 210.

In the case where the running time is smaller than the schedule time, the calculation result of "the schedule time - the running time" and the allowable error δT are compared with each other (Step 107a). When the difference therebetween is smaller than the allowable error δT, the formation of the end condition is established. In this case, the combination data of the target speeds and the running curve data both of which are temporarily stored are stored in the running plan data file 204 (Step 108a). Then, the processing for obtaining the optimal train running method is completed (Step 109a).

On the other hand, when the difference therebetween is more than the allowable errors δT, the processing for changing the target speed is performed (Step 110a). Then, the target speed in the territory having the positive and maximum ρ(n) is reduced by unit quantity, e.g., 1 km/h. After the subsequent target speed is newly set, a series of processing beginning from Step 104a are repeated.

With respect to the method of changing the target speed in Step 110a, in addition to the above-mentioned method, there are various ones which will subsequently be listed.

(1) A first method is such that as described on referring to the equation (4), $\underline{\rho}$ as the vector is used, its unit vector $\underline{\rho}/|\underline{\rho}|$ is obtained, the target speed is moved along the direction of that unit vector by unit quantity, and in a territory where the target velocity exceeds the limit speed, that target speed is not changed.
(2) A second method is such that since in the above method (1), the target speed will be increased in any territory having the negative ρ(n), $\underline{\rho}$ where $\underline{\rho}(n) = 0$ is set to that territory is used.
(3) A third method is such that since in the method described in the present embodiment and the above methods (1) and (2), there is the possibility that the increasing of the running time corresponding to the change of the target speed per unit quantity is large and thus it may not be suitably within the range of the allowable error, when approaching the running time set in advance, the target speed is changed to decrease the unit quantity.

Thus, in the method of producing a train running plan according to the second embodiment, the target speed in each of the limit speed territories is obtained for obtaining the train running plan, and the combination of the optimal target speeds is obtained by utilizing the ratio of the decreasing of the consumed energy to the increasing of the running time in the change of the target speed. Therefore, the number of parameters used for determining the target speed can be decreased and the computation time becomes less in comparison with the case of the method of obtaining the optimal running method over all the territories, such as the dynamic planning. Moreover, the present method can be applied

to the running pattern using the arbitrary limit speed. Further, since it is unnecessary to search for the minimum target speed within the limited area, the amount of calculation becomes less in comparison with the solution by the nonlinear planning.

When the limit sp ed of the train is changed, the running plan may be corrected so that the running time becomes the previously determined running time. Incidentally, as the system arrangement for carrying out the method of producing a train running plan, that shown in Fig. 11 is used. Therefore, the description of the system arrangement is omitted here for brevity. Then, only the features of the correction will hereinafter be described with reference to Fig. 17.

In Step 101b, the data of the starting position and the ending position of the limit speed changing territory (the territory 5 in Fig. 3A), and the change value of the limit speed are inputted.

In Step 102b, it is judged whether or not the change of the limit speed of the limit speed changing territory influences upon the target speed of that territory, i.e., whether or not that target speed is allowed in the newly set limit speed.

In the case of no influence thereupon, it is unnecessary to change the target speed, and thus the processing is completed (Step 103b). In the case where the influence is more or less present, a series of processing beginning from the Step 104b are carried out in the following manner.

Now, the preparation for giving the description of the series of processing from Step 104b will hereinunder be performed.

Fig. 18, Fig. 19, Fig. 20 and Fig. 21 are enlarged views of the territories 5 through 7 shown in Fig. 3A and Fig. 3B. Fig. 18 and Fig. 20 relate to the speed-and Fig. 19 and Fig. 21 relate to the running time density. Incidentally, it is assumed that the grade is zero over all the territories. The reason for setting the grade to zero was already discussed.

Fig. 18 and Fig. 19 show the running plan before the reduction of the limit speed of the territory 5, and Fig. 20 and Fig. 21 show the running plan after the reduction of the limit speed of the territory 5. In these figures, it is assumed that the limit speed of the territory n is $V_{MAX,n}$, the inverse number of $V_{MAX,i}$ is $\lambda_{MAX,i}$, the target speed is Vn, the inverse number of Vn is λn, the starting position of the territory is x_n, and the position where the switching over to the fixed speed running occurs is ξ_n. In Fig. 20 and Fig. 21, the change value is distinguished from the original value in Fig. 18 and Fig. 19 by putting "'" to the original value as shown in the form of ξ'.

In Step 104b, the target speed V_5' of the territory 5 where the limit speed is reduced is set to the maximum speed as fast as the train runs through the territory 5. This setting is performed for the purpose of recovering the delay as soon as possible to reduce the acceleration in the territory 6. Then, as the marginal speed which is set so as not to exceed the limit speed in the running is expressed by δv, and then the target speed is set in accordance with the relationship of $V_5' = V_{MAX,5}' - \delta v$. If the limit speed is 100 km/h for example, the marginal speed δv is set to about 3 km/h.

In Step 105b, it is judged whether or not a limit speed territory is present between the target speed changing territory, i.e., in this case, the territory 5 where the target speed is changed by the change of the limit speed, and the following station. In the case of absence of such a territory, there is no room for correction, and it is impossible to carry out the scheduled operation up to the following station (Step 106b).

In the case of presence of the limit speed territory, the processing proceeds to Step 107b. In Step 107b, it is judged whether or not the scheduled operation can be performed as the result of the correction of the target speed of the territory 6. The detail description will hereinbelow be given with respect to the judgement in Step 107b.

The running time T_1 of the territories 5 through 7 shown in Fig. 18 and Fig. 19 is expressed by the following equation using the equation (14) as already described.

$$T_1 = \lambda_4 \cdot (x_6 - x_5) + \lambda_4 \cdot (x_7 - x_6) + G(g^{-1}(\lambda_7)) - G(g^{-1}(\lambda_4)) + \lambda_7 \cdot (x_8 - \xi_7) \qquad (27)$$

Incidentally, the position ξ_7 in the territory 7 where the switching over to the fixed speed running is carried out is obtained from the following equation by utilizing the equation (15).

$$q^{-1}(V_7) - q^{-1}(V_4) = \xi_7 - x_7$$

The calculation of the running time T_2 of the territories 5 through 7 shown in Fig. 20 and Fig. 21 will subsequently be performed. Now, the target speed V_6' in the territory 6 is uncertain. Then, that target speed is determined so that the relationship of $T_2 = T_1$ is established.

Then, T_2 is calculated while leaving V_6' being an unknown quantity. Therefore, T_2 is a function of V_6'. Then, while ξ_6' and ξ_7' are also unknown quantities, they are uniquely determined if V_6' is determined. By using the equations (14) and (17), the following expression is obtained.

$$\begin{aligned} T_2 = {} & G(g^{-1}(\xi_5')) - G(g^{-1}(x_5)) + \lambda_5' \cdot (x_6 - \xi_5') + F(f^{-1}(\xi_6')) - F(f^{-1}(x_6)) \\ & + \lambda_6' \cdot (x_7 - \xi_6') + G(g^{-1}(\xi_7')) - G(g^{-1}(x_7)) + \lambda_7' \cdot (x_8 - \xi_7') \end{aligned} \qquad (28)$$

Incidentally, with respect to ξ_5', ξ_6' and ξ_7', the following relationships ar established.

$$q^{-1}(V_5') - q^{-1}(V_4) = \xi_5' - x_5$$

$$p^{-1}(V_6') - q^{-1}(V_5) = \xi_6' - x_6$$

$$q^{-1}(V_7') - q^{-1}(V_6) = \xi_7' - x_7$$

V_6' to be obtained can be calculated as the root of $\phi(V_l) = T_2(V_6')-T_1$ from the numerical calculation by utilizing the Newton's method or the like.

In the case where the solution of $\phi(V_6') = 0$ is present, it is judged in Step 107b that it is possible to perform the scheduled operation. At this time, the target speeds V_5 and V_6 are corrected to V_5' and V_6', respectively, to complete the processing (Step 108b). The resultant target speeds are displayed on the CRT 210. With the running curve, the data of the territories (the territories 5 through 7) where the correction occurs are replaced with those of the running curve (p(x) in Fig. 7 and q(x) in Fig. 8) when the grade is zero.

In the case of absence of the solution of $\phi(V_6') = 0$, it is judged in Step 107b that it is impossible to perform the scheduled operation by only the correction of the territories 5 and 6. At this time, in the same manner as in V_5', V_6' is also set to the maximum speed as fast as the train runs through the territory 6 (Step 109b). Then, the processing is returned to the Step 105b to perform the calculation for obtaining V_7'.

In the above-mentioned algorithum, in the case where the correction is necessary for the fairly foward territories such as the territories 7 and 8, the amount of calculation is increased so that the calculation requires much time. However, since the target speed of the nearest territory is set to the maximum speed as fast as the train runs through that territory, the predetermined calculation may be completed during the running through that territory. Thus, there is no problem in practical use.

As described above, according to the method of correcting a train running plan, the data which are calculated in advance by the simulation are used to perform the calculation of the running time, thereby to perform the correction of the running plan. Therefore, even when the change of the limit speed occurs temporarily, the running plan can be corrected in a real-time manner.

Claims

1. A method of producing a train running plan for making a train to run through a predetermined travel territory of a railway, wherein the travel territory is divided into a plurality of territories, each having a predetermined limit speed ($V_{MAX,i}$), while maintaining a predetermined running time (T_D), the method comprising the steps of:

   (a) setting a target speed for each territory;
   (b) obtaining a consumed energy (E) and a running time (T), wherein the train is simulated to run in accordance with the target speeds in each territory, assuming acceleration of the train by a maximum accelerating force and deceleration of the train by a maximum decelerating force;
   (c) for each territory, without altering the target speeds of the other territories, reducing the target speed of a territory and obtaining a consumed energy (E') and a running time (T') for the changed target speed of the territory, and determining a change ratio of the consumed energy obtained for the territory; and
   (d) repeating steps (b) and (c), wherein, after each step (c), the target speeds are reset on the basis of the change ratios, in order to determine the target speeds of all the territories in the predetermined travel territory in such a way that, in the simulation, the train runs in accordance with said predetermined running time and the consumed energy becomes minimum.

2. The method according to claim 1, wherein step (c) comprises the steps of

   (c_1) determining the change ratio of the consumed energy for each territory as positive for the case that the consumed energy is decreased while the running time is increased, wherein the target speed initially set in step (a) is assumed to be the limit speed;
   (c_2) reducing the target speed of the territory, in which the resultant change ratio of the consumed energy takes the maximum value, by unit quantity; and
   (c_3) treating the target speed reduced by unit quantity in step (c_2) as a new target speed, when the running time is within a predetermined error range.

3. The method according to claim 2, wherein step (c_2) includes a processing of the value of the change ratio of the consumed energy obtained for each territory as a vector quantity to change the target speed along the direction of

the vector by unit quantity.

4. The method according to claim 3, wherein said processing as a vector quantity includes a changing of a component of the vector quantity of the territory to "0" if the component of the vector quantity is negative.

5. The method according to claim 2, wherein step (c_2) includes a process of decreasing the unit quantity for changing the target speed, when the running time of the train in the territory approaches the predetermined running time.

6. The method according to claim 1, wherein the running time and the consumed energy of the train of the predetermined travel territory are obtained on the basis of an initial speed when the train enters into said travel territory, predetermined grade information, a running resistance of the train, acceleration and deceleration characteristics of the train and a weight of the train.

7. The method according to claim 6, wherein the consumed energy is made to be an evaluation function (E) expressed by an equation of $E = E(V_1, ..., V_N)$ wherein the individual target speeds are independent variables $(V_1, ..., V_N)$.

8. The method according to claim 7, wherein the running time is made to be evaluation function (T) expressed by equation $T = T(V_1, ..., V_N)$.

9. The method according to claim 7 or 8, wherein a differential coefficient is obtained from an approximate expression of $\partial E/\partial V(n) = \Delta E/\Delta V(n)$, wherein target speed V(n) is changed in the range of $0 \leq V(n) \leq Vmax(n)$ and V(n) becomes an optimal target speed when E takes a minimum value.

Patentansprüche

1. Verfahren zum Erstellen eines Zugfahrplans, um einen Zug durch ein vorbestimmtes Reisegebiet eines Eisenbahnnetzes fahren zu lassen, wobei das Reisegebiet in eine Vielzahl von Gebieten unterteilt ist, die jedes eine vorbestimmte Höchstgeschwindigkeit ($V_{max,\,i}$) besitzt, während eine vorbestimmte Fahrzeit (T_D) aufrechterhalten wird, mit den Schritten

   (a) Festlegen einer Zielgeschwindigkeit für jedes Gebiet;
   (b) Bestimmen der verbrauchten Energie (E) und der Fahrzeit (T), wobei simuliert wird, daß der Zug in Übereinstimmung mit den Zielgeschwindigkeiten in jedem Gebiet fährt unter der Annahme einer Beschleunigung des Zuges mit einer maximalen Beschleunigungskraft und einer Abbremsung des Zuges mit einer maximalen Abbremskraft;
   (c) für jedes Gebiet, Verringern der Zielgeschwindigkeit eines Gebietes, ohne die Zielgeschwindigkeiten der anderen Gebiete zu verändern, und Ermitteln der verbrauchten Energie (E') und der Fahrzeit (T') für die geänderte Zielgeschwindigkeit des Gebietes und Bestimmen eines Veränderungsquotienten der für das Gebiet ermittelten, verbrauchten Energie; und
   (d) Wiederholen der Schritte (b) und (c), wobei nach jedem Schritt (c) die Zielgeschwindigkeiten auf der Grundlage der Änderungsquotienten neu festgelegt werden, um die Zielgeschwindigkeiten aller Gebiete in dem vorbestimmten Reisegebiet auf eine solche Weise zu bestimmen, daß bei der Simulation der Zug in Übereinstimmung mit der vorbestimmten Fahrzeit fährt und die verbrauchte Energie minimal wird.

2. Verfahren gemäß Anspruch 1, wobei der Schritt (c) die Schritte

   (c_1) Bestimmen des Änderungsquotienten der verbrauchten Energie für jedes Gebiet als positiv, wenn die verbrauchte Energie abnimmt, während die Fahrzeit zunimmt, wobei die anfänglich in Schritt (a) festgelegte Zielgeschwindigkeit als Höchstgeschwindigkeit angesehen wird;
   (c_2) Verringern der Zielgeschwindigkeit des Gebietes, in dem der resultierende Änderungsquotient der verbrauchten Energie den maximalen Wert annimmt, um einen Einheitswert; und
   (c_3) Behandeln der um den Einheitswert in Schritt (c_2) verringerten Zielgeschwindigkeit als neue Zielgeschwindigkeit, wenn die Fahrzeit innerhalb eines vorbestimmten Fehlerbereichs liegt.

3. Verfahren gemäß Anspruch 2, wobei der Schritt (c_2) ein Verarbeiten des Wertes des Änderungsquotienten der für jedes Gebiet ermittelten verbrauchten Energie als Vektorgröße, um die Zielgeschwindigkeit entlang der Richtung des Vektors um den Einheitswert zu ändern.

4. Verfahren gemäß Anspruch 3, wobei das Verarbeiten einer Vektorgroße ein Ändern einer Komponente der Vektorgröße des Gebietes auf "0" enthält, wenn die Komponente der Vektorgröße negativ ist.

5. Verfahren gemäß Anspruch 2, wobei der Schritt (c_2) einen Vorgang des Verringerns des Einheitswerts zum Ändern der Zielgeschwindigkeit enthält, wenn die Fahrzeit des Zuges in dem Gebiet sich der vorbestimmten Fahrzeit nähert.

6. Verfahren gemäß Anspruch 1, wobei die Fahrzeit und die verbrauchte Energie des Zuges in dem vorbestimmten Reisegebiet auf der Grundlage einer Eingangsgeschwindigkeit, wenn der Zug in das Reisegebiet einfährt, einer vorbestimmten Steigungsinformation, eines Fahrwiderstands des Zuges, einer Beschleunigungs- und Abbremscharacteristik des Zuges und eines Gewichts des Zuges erhalten wird.

7. Verfahren gemäß Anspruch 6, wobei die verbrauchte Energie als Auswertefunktion (E), ausgedrückt durch eine Gleichung $E = E(V_1, \ldots, V_N)$, wobei die einzelnen Zielgeschwindigkeiten unabhängige Variablen ($V_1, \ldots, V_N$) sind, behandelt wird.

8. Verfahren gemäß Anspruch 7, wobei die Fahrzeit als Auswertefunktion (T), ausgedrückt durch die Gleichung $T = T(V_1, \ldots, V_N)$, behandelt wird.

9. Verfahren gemäß Anspruch 7 oder 8, wobei der Differentialkoeffizient von einem Näherungsausdruck von $\delta E/\delta V(n) = \Delta E/\Delta V(n)$ erhalten wird, wobei die Zielgeschwindigkeit V(n) im Bereich von $0 \leq V(n) \leq V_{max}(n)$ geändert wird und V(n) die optimale Zielgeschwindigkeit ist, wenn E einen minimalen Wert annimmt.

Revendications

1. Procédé de production d'un plan de circulation de train pour faire circuler un train à travers un tronçon de déplacement prédéterminé d'une voie de chemin de fer dans lequel le tronçon de déplacement est divisé en plusieurs tronçons, ayant chacun une vitesse limite prédéterminée ($V_{MAX,i}$), tout en maintenant un temps de circulation prédéterminé (T_D), le procédé comportant les étapes consistant à :

   (a) établir une vitesse cible pour chaque tronçon ;
   (b) obtenir une énergie consommée (E) et un temps de circulation (T), dans lesquels on simule que le train circule conformément aux vitesses cibles de chaque tronçon, en supposant que le train est accéléré par une force d'accélération maximale et que le train est décéléré par une force de décélération maximale ;
   (c) pour chaque tronçon, sans faire varier les vitesses cibles des autres tronçons, réduire la vitesse cible du tronçon et, obtenir une énergie consommée (E') et un temps de circulation (T') pour la vitesse cible changée du tronçon, et déterminer un rapport de changement de l'énergie consommée obtenu pour le tronçon ; et
   (d) répéter les étapes (b) et (c), les vitesses cibles, après chaque étape (c), étant réinitialisées sur la base des rapports de changement afin de déterminer les vitesses cibles de tous les tronçons du tronçon de déplacement prédéterminé de telle sorte que, dans la simulation, le train circule conformément audit temps de circulation prédéterminé et l'énergie consommée devient minimale.

2. Procédé selon la revendication 1, dans lequel l'étape (c) comporte les étapes consistant à :

   (c_1) déterminer le rapport de changement de l'énergie consommée pour chaque tronçon comme étant positif dans le cas où l'énergie consommée diminue alors que le temps de circulation est augmenté, la vitesse cible établie initialement à l'étape (a) étant supposée être la vitesse limite ;
   (c_2) réduire la vitesse cible du tronçon, dans lequel le rapport de changement résultant de l'énergie consommée prend la valeur maximale, d'une quantité unitaire ; et
   (c_3) traiter la vitesse cible réduite d'une quantité unitaire dans l'étape (c_2) en tant que nouvelle vitesse cible, lorsque le temps de circulation est dans une plage d'erreurs prédéterminée.

3. Procédé selon la revendication 2, dans lequel l'étape (c_2) comporte un traitement de la valeur du rapport de changement de l'énergie consommée obtenu pour chaque tronçon en tant que grandeur vectorielle pour changer la vitesse cible le long de la direction du vecteur d'une quantité unitair .

4. Procédé selon la revendication 3, dans lequel ledit traitement en tant que grandeur vectorielle comporte le changement d'une composante de la grandeur vectorielle du tronçon à "0" si la composante de la grandeur vectorielle est négative.

5. Procédé selon la revendication 2, dans lequel l'étape (c_2) comporte un traitement de diminution de la quantité unitaire pour changer la vitesse cible, lorsque l temps de circulation du train dans le tronçon approch l temps d circulation prédéterminé.

6. Procédé selon la revendication 1, dans lequel le temps de circulation et l'énergie consommée du train du tronçon de déplacement prédéterminé sont obtenus sur la base de la vitesse initiale lorsque le train pénètre dans ledit tronçon de déplacement, d'une information de déclivité prédéterminée, d'une résistance à la circulation du train, des caractéristiques d'accélération et de décélération du train et du poids du train.

7. Procédé selon la revendication 6, dans lequel l'énergie consommée est amenée à être une fonction d'évaluation (E) exprimée par l'équation $E = E(V_1, ..., V_N)$ dans laquelle les vitesses cibles individuelles sont des variables indépendantes ($V_1, ..., V_N$).

8. Procédé selon la revendication 7, dans lequel le temps de circulation est amené à être une fonction d'évaluation (T) exprimée par l'équation $T = T(V_1, ..., V_N)$.

9. Procédé selon la revendication 7 ou 8, dans lequel un coefficient différentiel est obtenu à partir d'une expression approchée de $\delta E/\delta V(n) = \Delta E/\Delta V(n)$, la vitesse cible V(n) étant changée dans la plage de $0 \leq V(n) \leq Vmax(n)$ et V(n) étant une vitesse cible optimale lorsque E a une valeur minimale.

FIG. 1 PRIOR ART

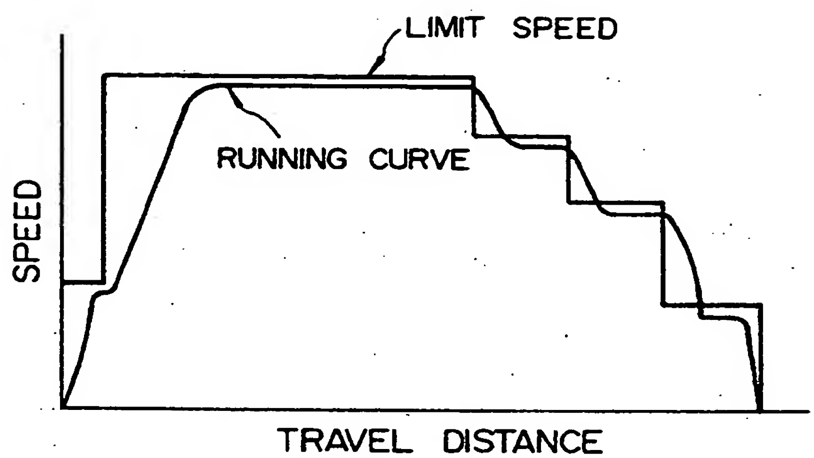


FIG. 2

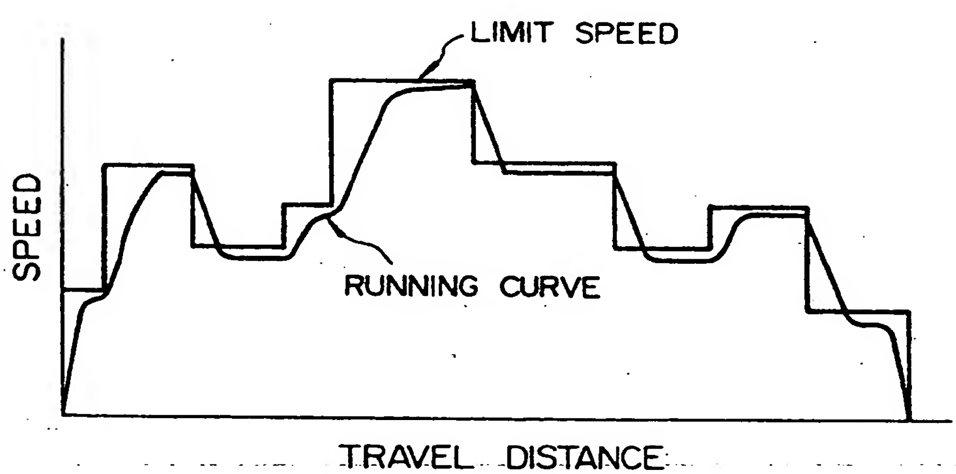


FIG. 3A

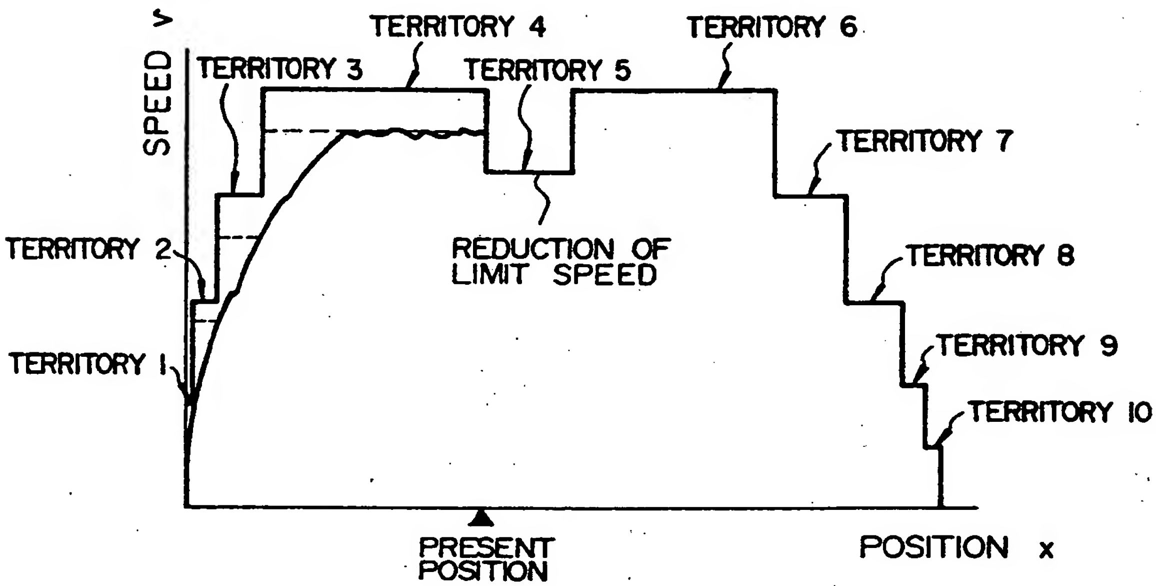

SPEED v
TERRITORY 1
TERRITORY 2
TERRITORY 3
TERRITORY 4
TERRITORY 5
TERRITORY 6
TERRITORY 7
TERRITORY 8
TERRITORY 9
TERRITORY 10
REDUCTION OF LIMIT SPEED
PRESENT POSITION
POSITION x

FIG. 3B

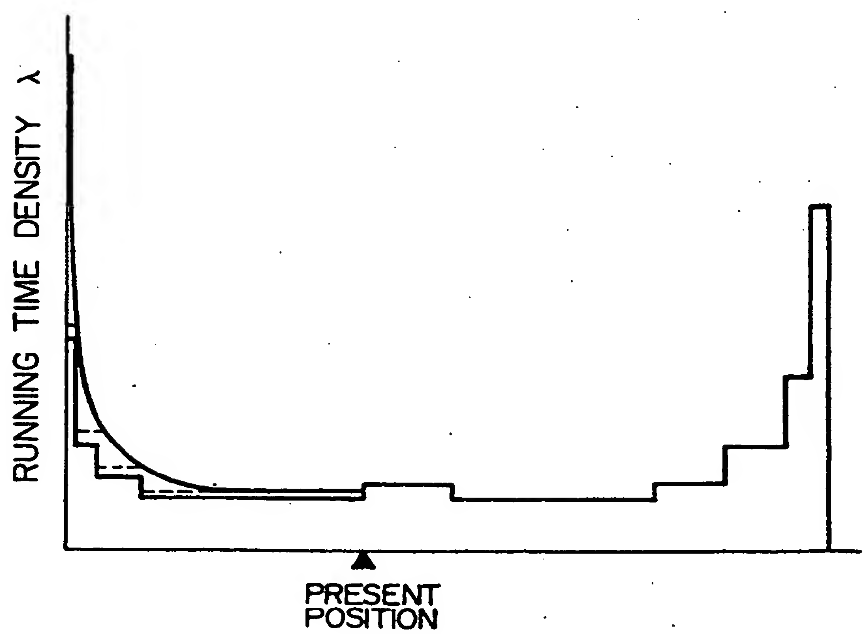

RUNNING TIME DENSITY λ
PRESENT POSITION

FIG. 4

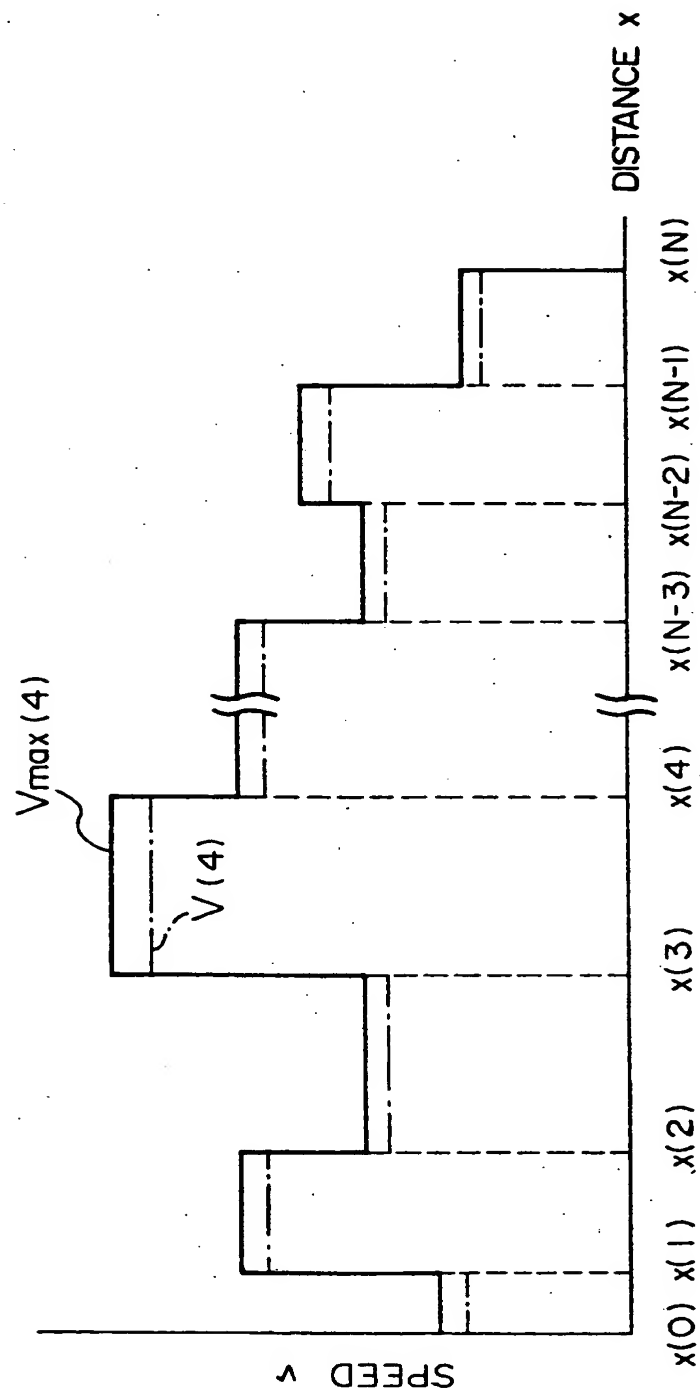


FIG. 5

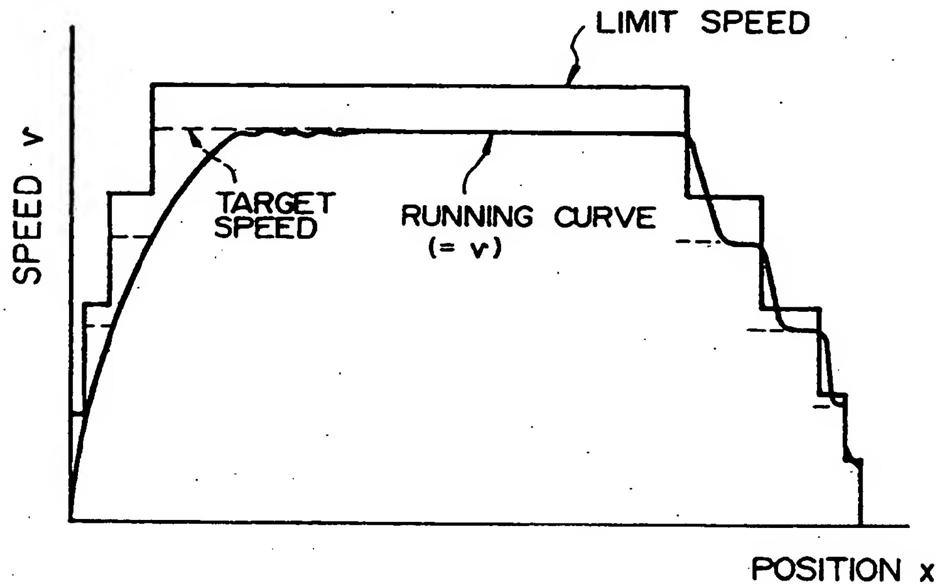

LIMIT SPEED
SPEED v
TARGET SPEED
RUNNING CURVE (= v)
POSITION x

FIG. 6

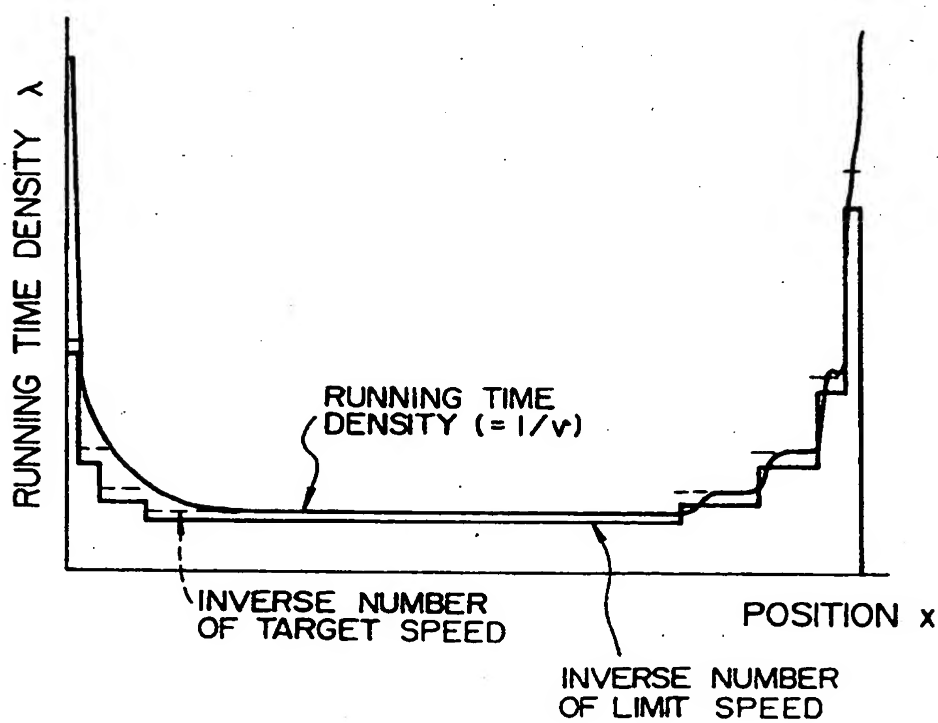

RUNNING TIME DENSITY λ
RUNNING TIME DENSITY (= 1/v)
INVERSE NUMBER OF TARGET SPEED
POSITION x
INVERSE NUMBER OF LIMIT SPEED

FIG. 7

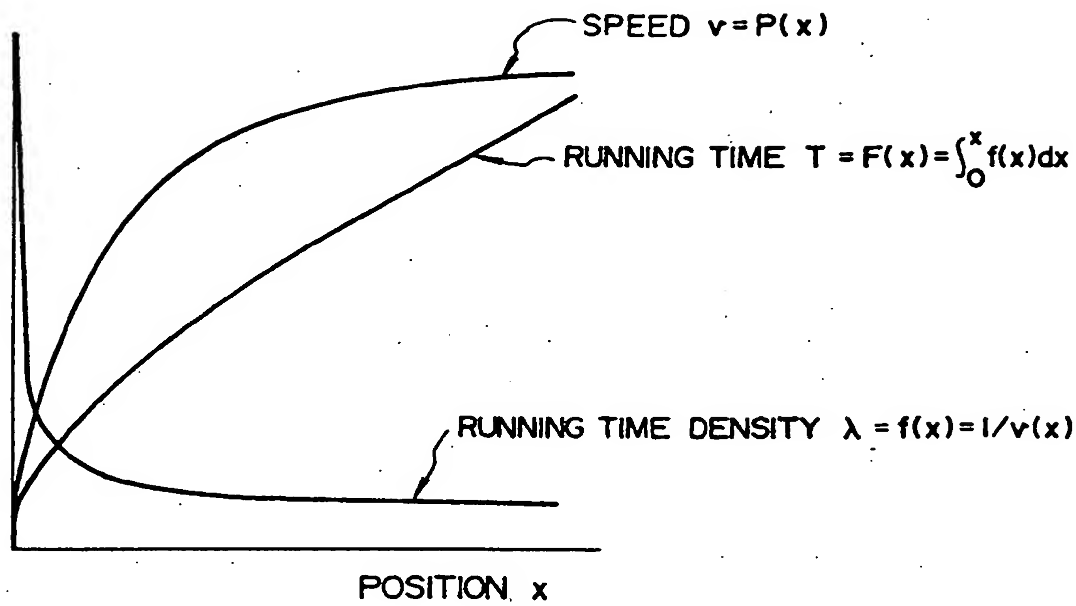

SPEED v=P(x)
RUNNING TIME T = F(x) = $\int_0^x f(x)dx$
RUNNING TIME DENSITY λ = f(x) = 1/v(x)
POSITION x

FIG. 8

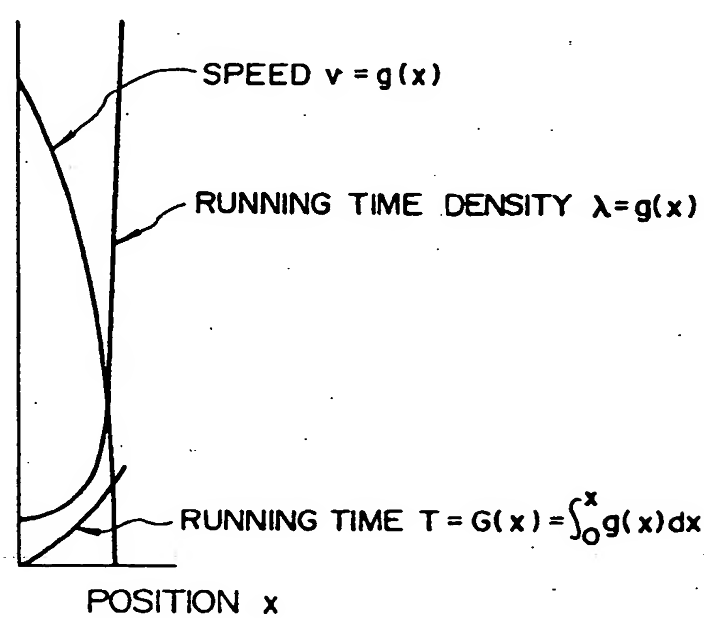

SPEED v = g(x)
RUNNING TIME DENSITY λ = g(x) = 1/v(x)
RUNNING TIME T = G(x) = $\int_0^x g(x)dx$
POSITION x

FIG. 9

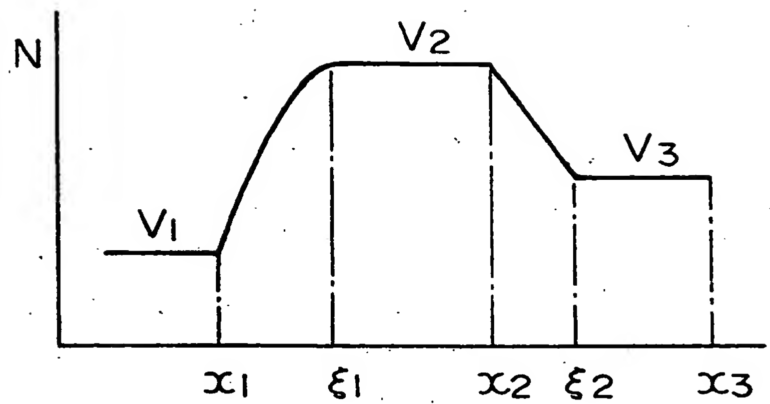


FIG. 10

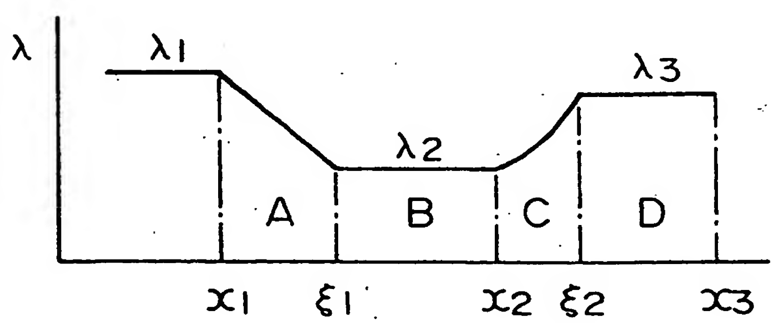
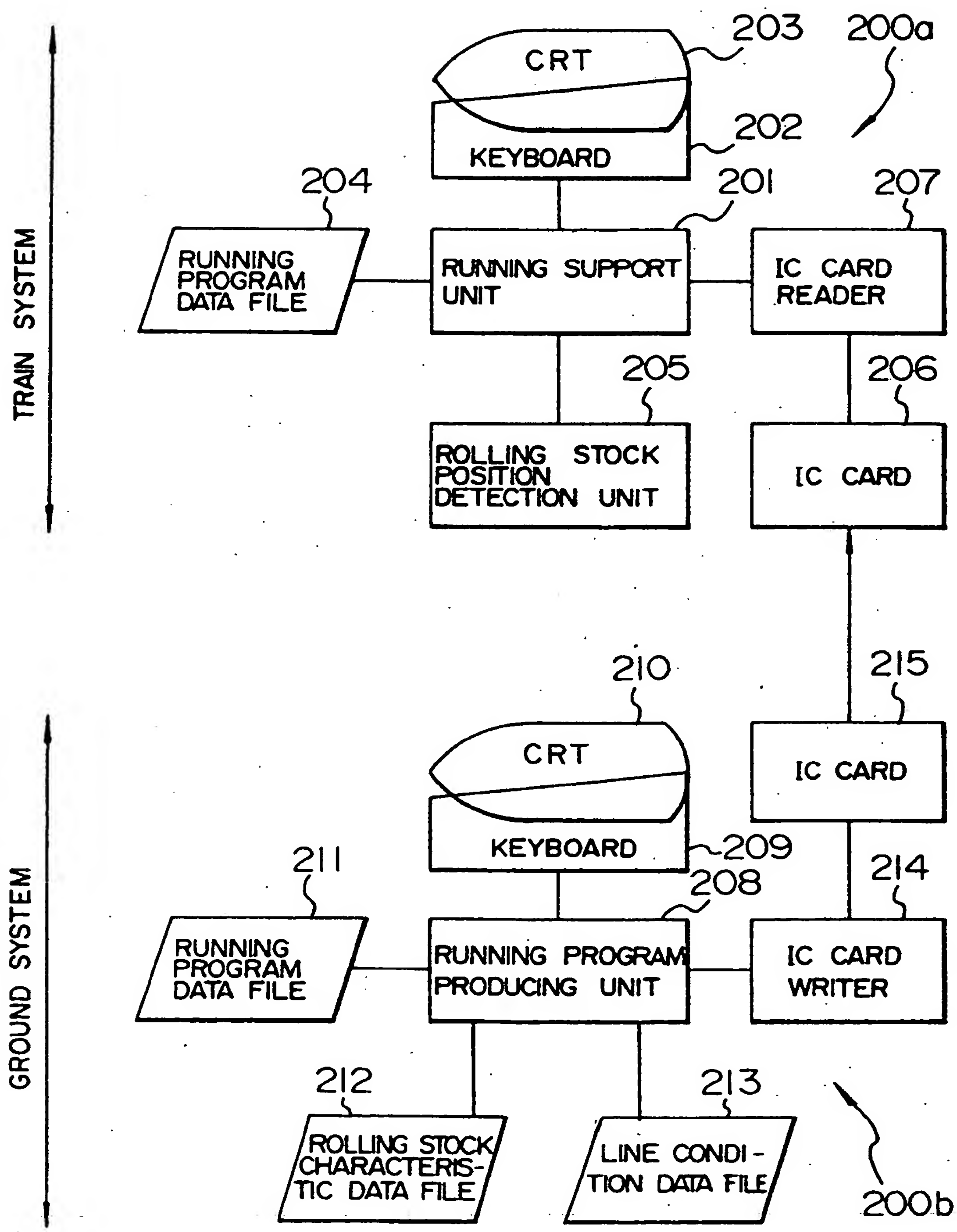


FIG. 11



TRAIN SYSTEM
GROUND SYSTEM
CRT
KEYBOARD
203
200a
202
201
204
207
RUNNING PROGRAM DATA FILE
RUNNING SUPPORT UNIT
IC CARD READER
205
206
ROLLING STOCK POSITION DETECTION UNIT
IC CARD
210
215
CRT
IC CARD
KEYBOARD
209
208
211
214
RUNNING PROGRAM DATA FILE
RUNNING PROGRAM PRODUCING UNIT
IC CARD WRITER
212
213
ROLLING STOCK CHARACTERIS-TIC DATA FILE
LINE CONDI-TION DATA FILE
200b

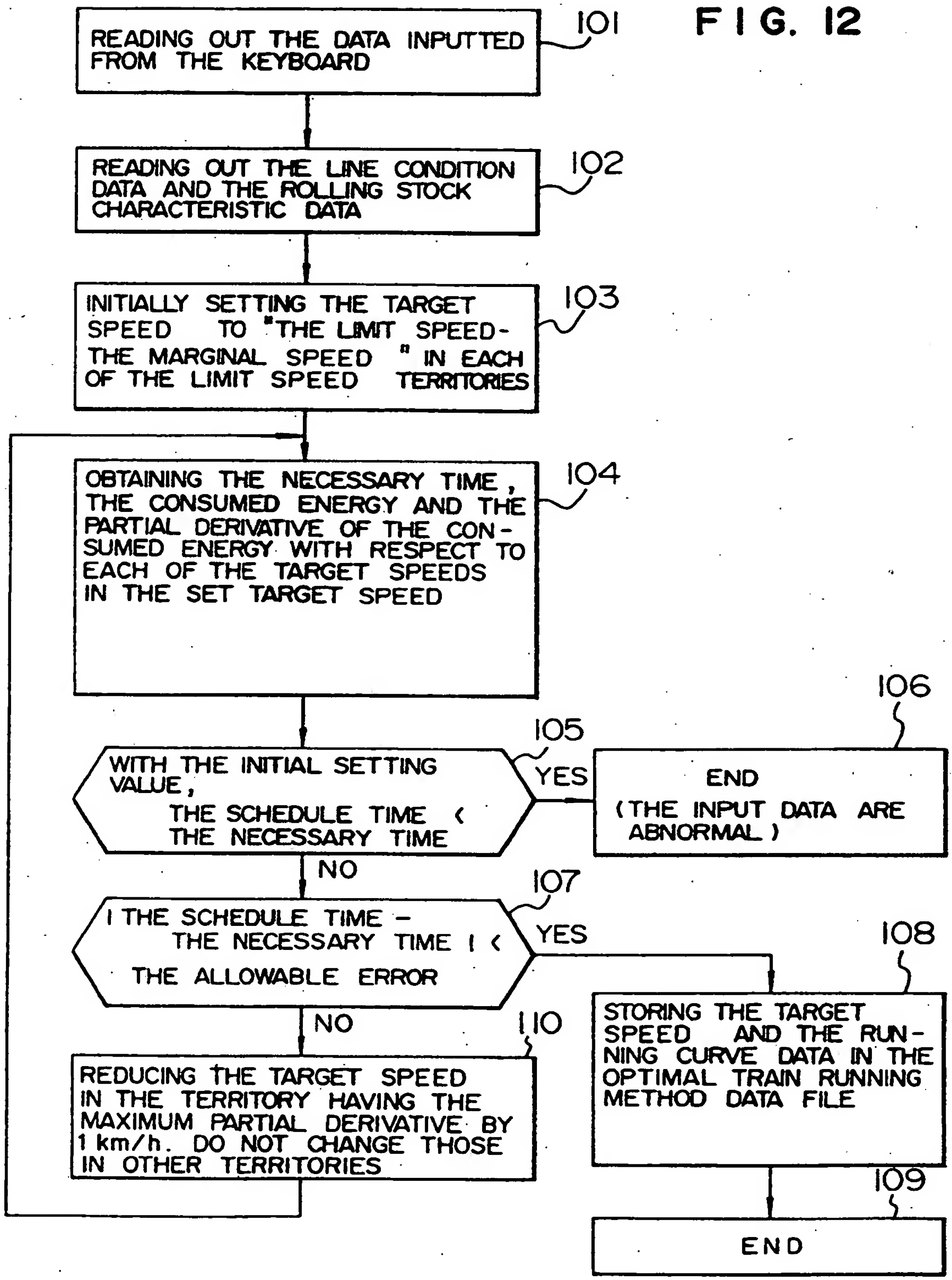

READING OUT THE DATA INPUTTED FROM THE KEYBOARD
101
READING OUT THE LINE CONDITION DATA AND THE ROLLING STOCK CHARACTERISTIC DATA
102
INITIALLY SETTING THE TARGET SPEED TO "THE LIMIT SPEED - THE MARGINAL SPEED " IN EACH OF THE LIMIT SPEED TERRITORIES
103
OBTAINING THE NECESSARY TIME, THE CONSUMED ENERGY AND THE PARTIAL DERIVATIVE OF THE CONSUMED ENERGY WITH RESPECT TO EACH OF THE TARGET SPEEDS IN THE SET TARGET SPEED
104
WITH THE INITIAL SETTING VALUE, THE SCHEDULE TIME < THE NECESSARY TIME
105
YES
END (THE INPUT DATA ARE ABNORMAL)
106
NO
\| THE SCHEDULE TIME - THE NECESSARY TIME \| < THE ALLOWABLE ERROR
107
YES
STORING THE TARGET SPEED AND THE RUNNING CURVE DATA IN THE OPTIMAL TRAIN RUNNING METHOD DATA FILE
108
NO
REDUCING THE TARGET SPEED IN THE TERRITORY HAVING THE MAXIMUM PARTIAL DERIVATIVE BY 1 km/h. DO NOT CHANGE THOSE IN OTHER TERRITORIES
110
END
109

FIG. 12

FIG. 13

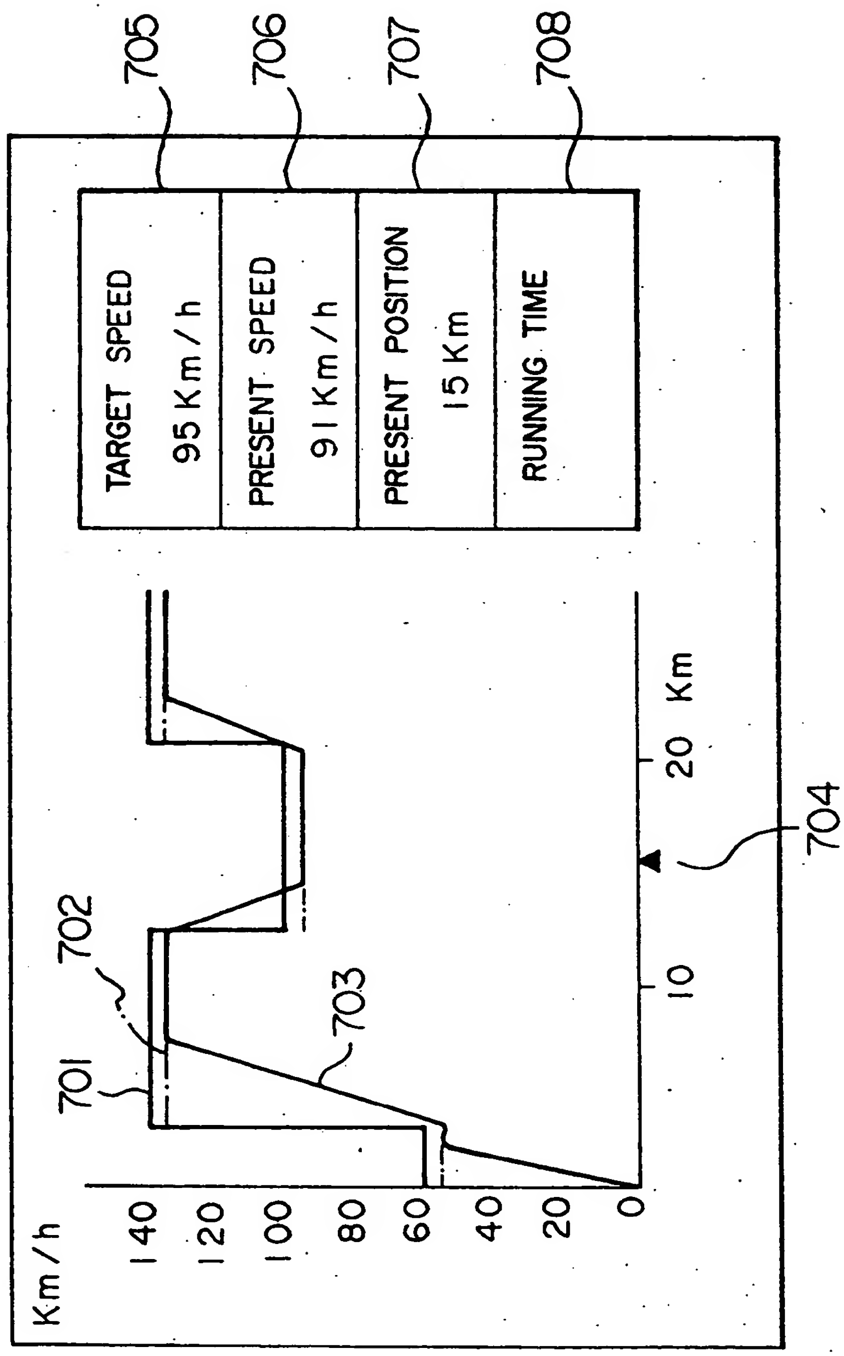

TARGET SPEED
95 Km/h
PRESENT SPEED
91 Km/h
PRESENT POSITION
15 Km
RUNNING TIME
705
706
707
708
Km/h
140
120
100
80
60
40
20
0
10
20 Km
701
702
703
704

FIG. 14

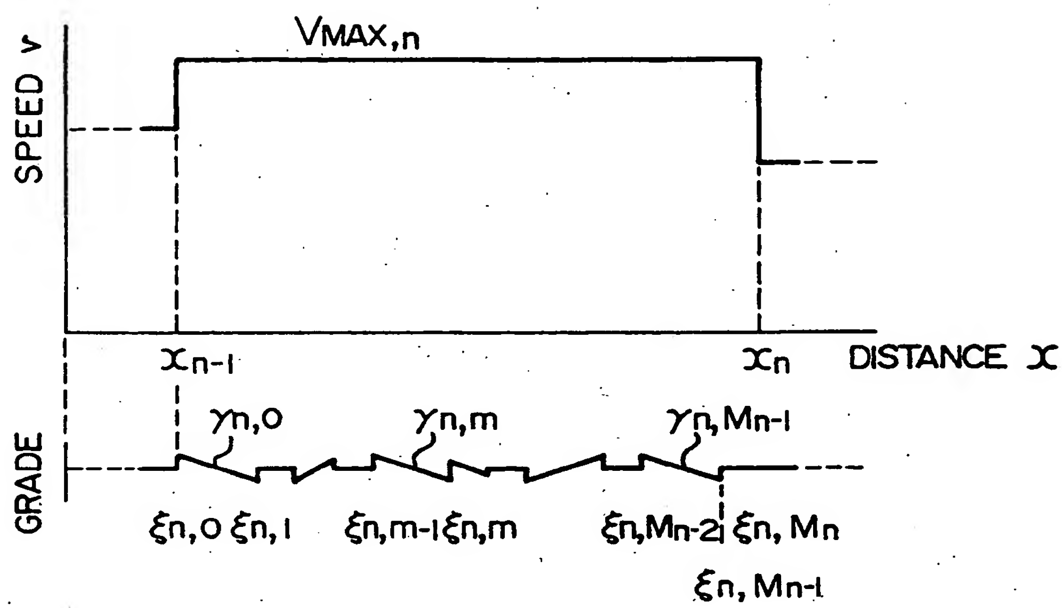
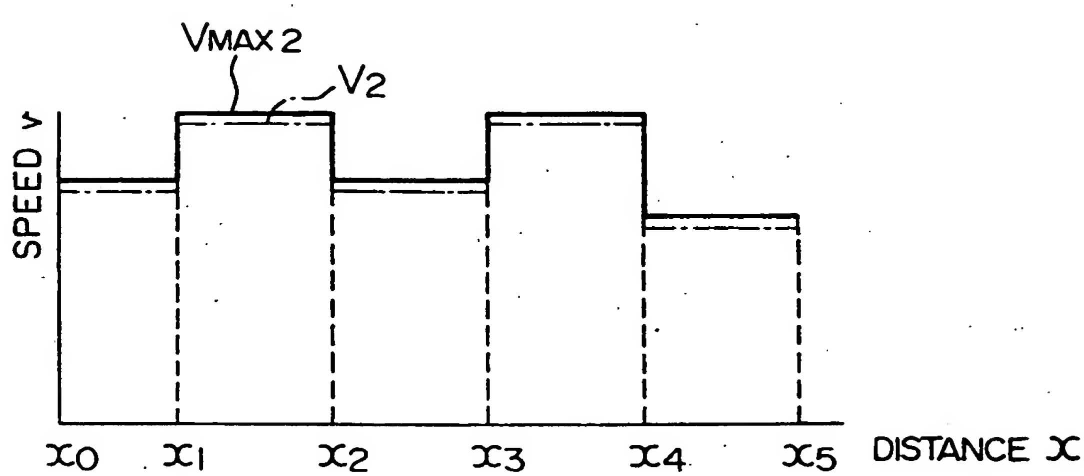

VMAX,n
SPEED v
GRADE
xn-1
xn
DISTANCE x
γn,0
γn,m
γn,Mn-1
ξn,0 ξn,1
ξn,m-1 ξn,m
ξn,Mn-2 ξn, Mn
ξn, Mn-1

FIG. 15


VMAX 2
V2
SPEED v
x0
x1
x2
x3
x4
x5
DISTANCE x

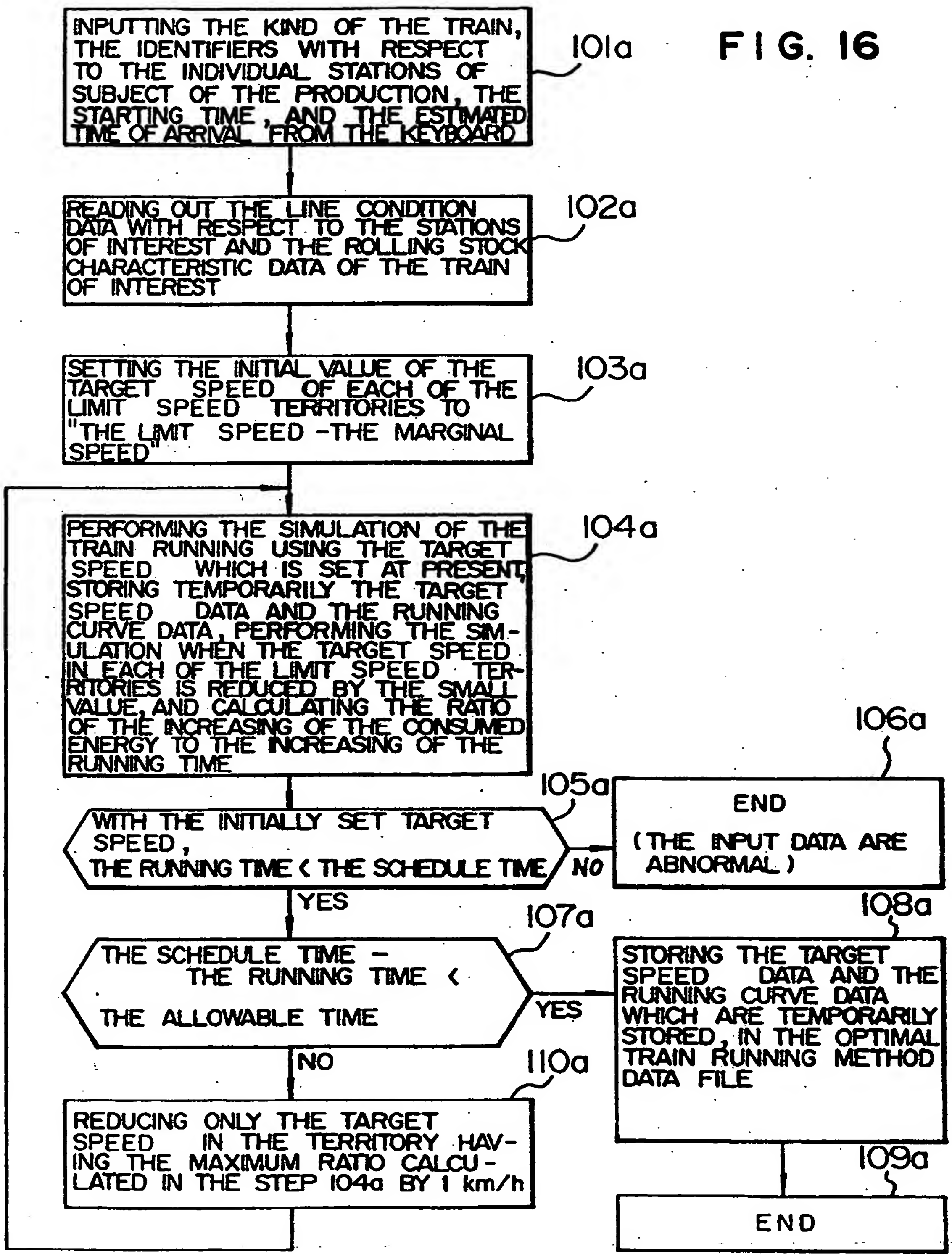

INPUTTING THE KIND OF THE TRAIN, THE IDENTIFIERS WITH RESPECT TO THE INDIVIDUAL STATIONS OF SUBJECT OF THE PRODUCTION, THE STARTING TIME, AND THE ESTIMATED TIME OF ARRIVAL FROM THE KEYBOARD
101a
READING OUT THE LINE CONDITION DATA WITH RESPECT TO THE STATIONS OF INTEREST AND THE ROLLING STOCK CHARACTERISTIC DATA OF THE TRAIN OF INTEREST
102a
SETTING THE INITIAL VALUE OF THE TARGET SPEED OF EACH OF THE LIMIT SPEED TERRITORIES TO "THE LIMIT SPEED -THE MARGINAL SPEED"
103a
PERFORMING THE SIMULATION OF THE TRAIN RUNNING USING THE TARGET SPEED WHICH IS SET AT PRESENT, STORING TEMPORARILY THE TARGET SPEED DATA AND THE RUNNING CURVE DATA, PERFORMING THE SIMULATION WHEN THE TARGET SPEED IN EACH OF THE LIMIT SPEED TERRITORIES IS REDUCED BY THE SMALL VALUE, AND CALCULATING THE RATIO OF THE INCREASING OF THE CONSUMED ENERGY TO THE INCREASING OF THE RUNNING TIME
104a
WITH THE INITIALLY SET TARGET SPEED, THE RUNNING TIME < THE SCHEDULE TIME
105a
NO
106a
END (THE INPUT DATA ARE ABNORMAL)
YES
THE SCHEDULE TIME − THE RUNNING TIME < THE ALLOWABLE TIME
107a
YES
108a
STORING THE TARGET SPEED DATA AND THE RUNNING CURVE DATA WHICH ARE TEMPORARILY STORED, IN THE OPTIMAL TRAIN RUNNING METHOD DATA FILE
NO
110a
REDUCING ONLY THE TARGET SPEED IN THE TERRITORY HAVING THE MAXIMUM RATIO CALCULATED IN THE STEP 104a BY 1 km/h
109a
END

FIG. 16

FIG. 17

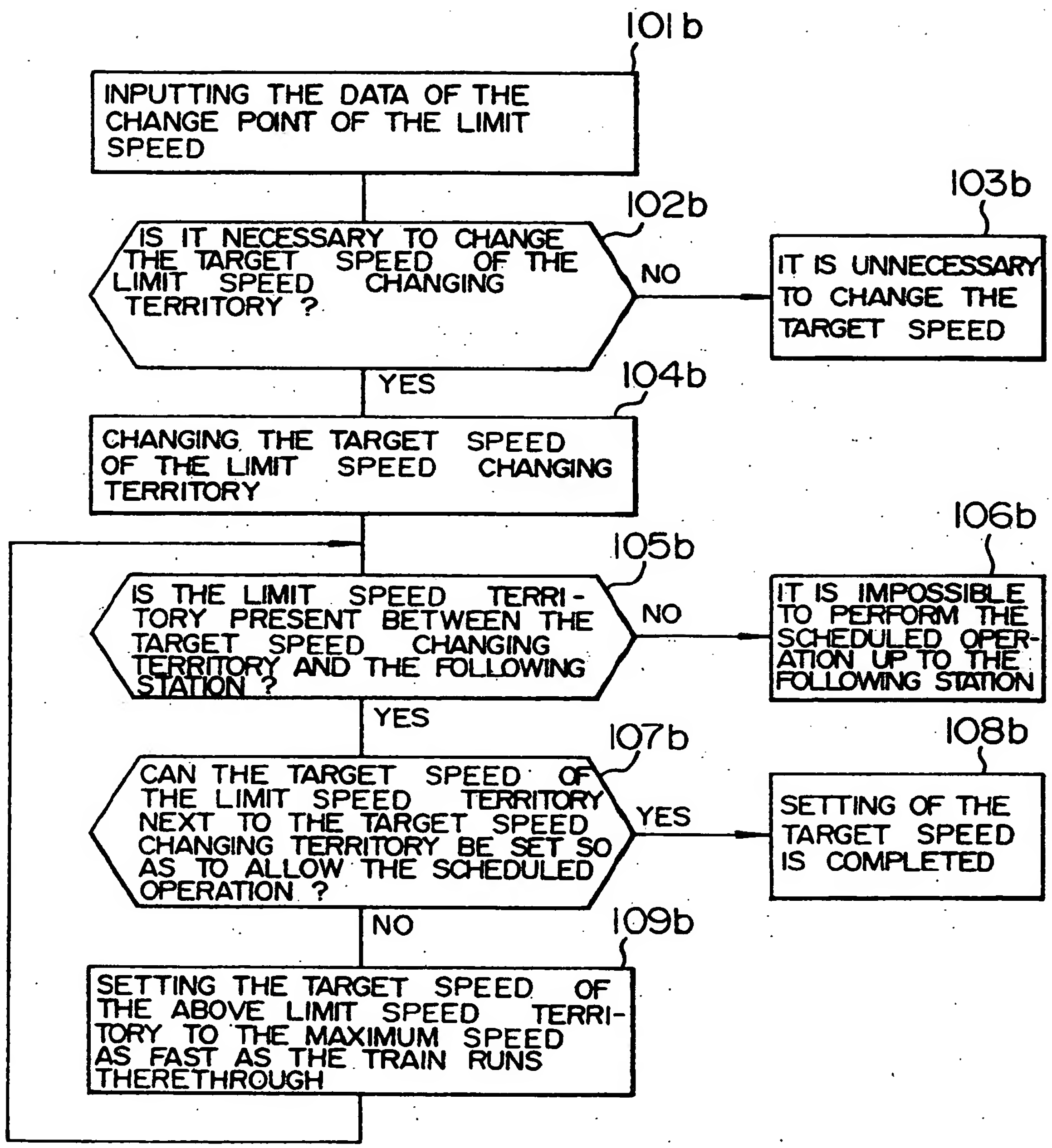

101b
INPUTTING THE DATA OF THE CHANGE POINT OF THE LIMIT SPEED
102b
IS IT NECESSARY TO CHANGE THE TARGET SPEED OF THE LIMIT SPEED CHANGING TERRITORY ?
NO
103b
IT IS UNNECESSARY TO CHANGE THE TARGET SPEED
YES
104b
CHANGING THE TARGET SPEED OF THE LIMIT SPEED CHANGING TERRITORY
105b
IS THE LIMIT SPEED TERRITORY PRESENT BETWEEN THE TARGET SPEED CHANGING TERRITORY AND THE FOLLOWING STATION ?
NO
106b
IT IS IMPOSSIBLE TO PERFORM THE SCHEDULED OPERATION UP TO THE FOLLOWING STATION
YES
107b
CAN THE TARGET SPEED OF THE LIMIT SPEED TERRITORY NEXT TO THE TARGET SPEED CHANGING TERRITORY BE SET SO AS TO ALLOW THE SCHEDULED OPERATION ?
YES
108b
SETTING OF THE TARGET SPEED IS COMPLETED
NO
109b
SETTING THE TARGET SPEED OF THE ABOVE LIMIT SPEED TERRITORY TO THE MAXIMUM SPEED AS FAST AS THE TRAIN RUNS THERETHROUGH

FIG. 18

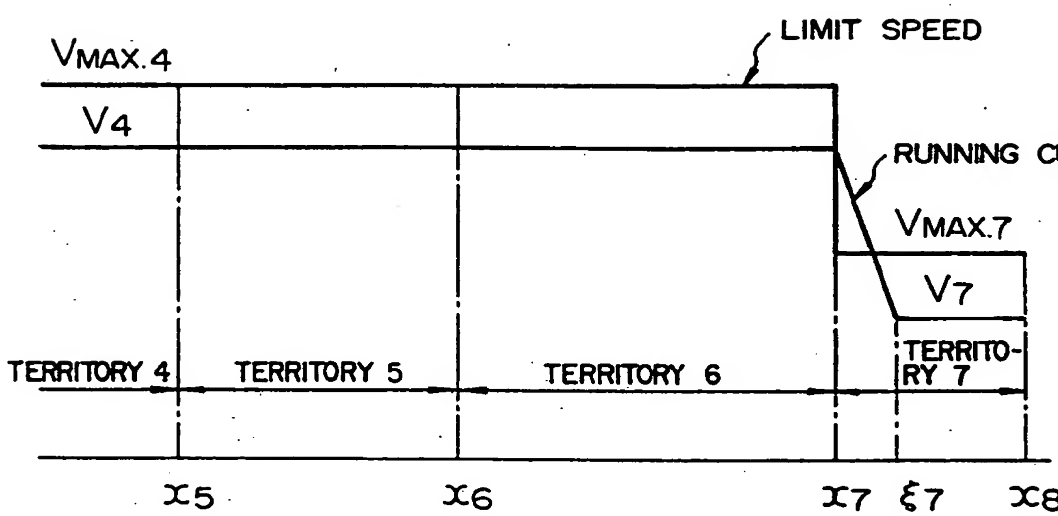

LIMIT SPEED
VMAX.4
V4
RUNNING CURVE
VMAX.7
V7
TERRITORY 4
TERRITORY 5
TERRITORY 6
TERRITO-RY 7
x5
x6
x7
ξ7
x8

FIG. 19

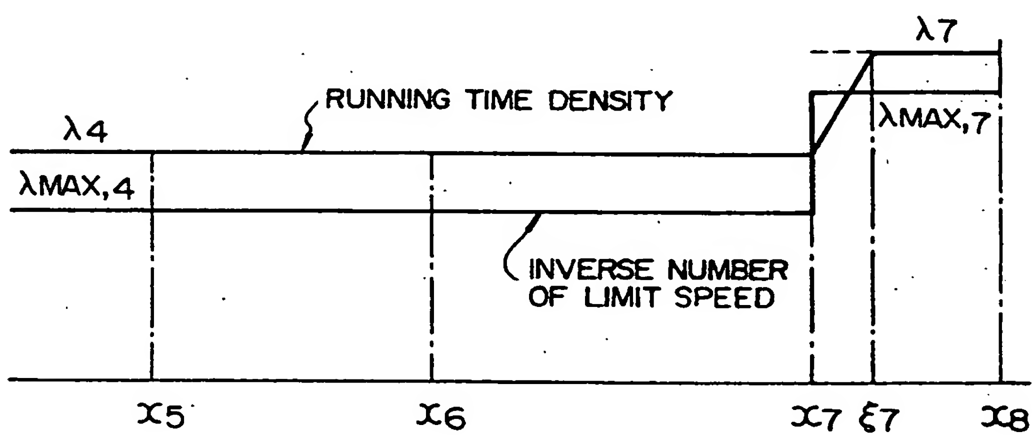

λ7
RUNNING TIME DENSITY
λ4
λMAX,7
λMAX,4
INVERSE NUMBER OF LIMIT SPEED
x5
x6
x7
ξ7
x8

FIG. 20

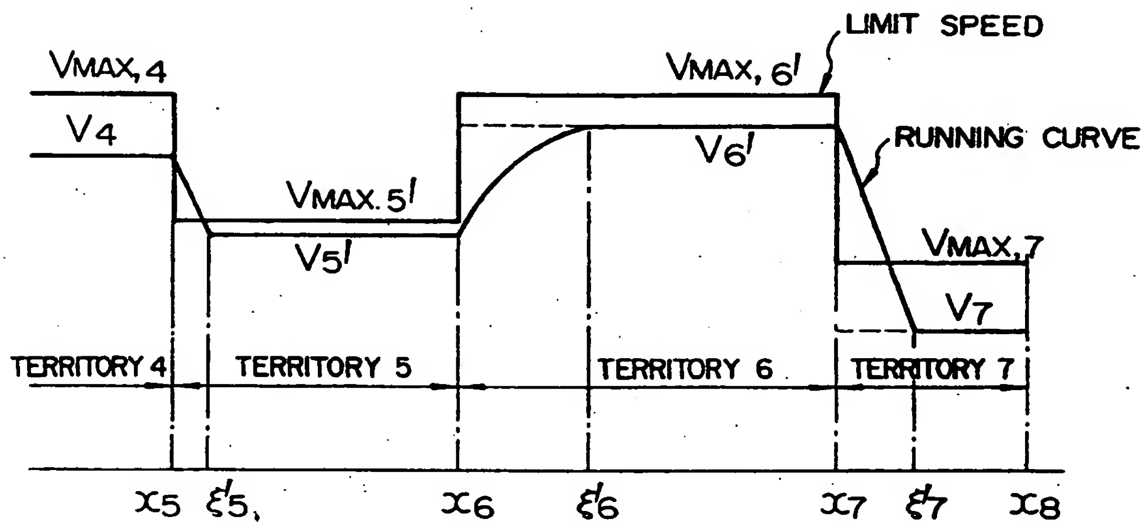
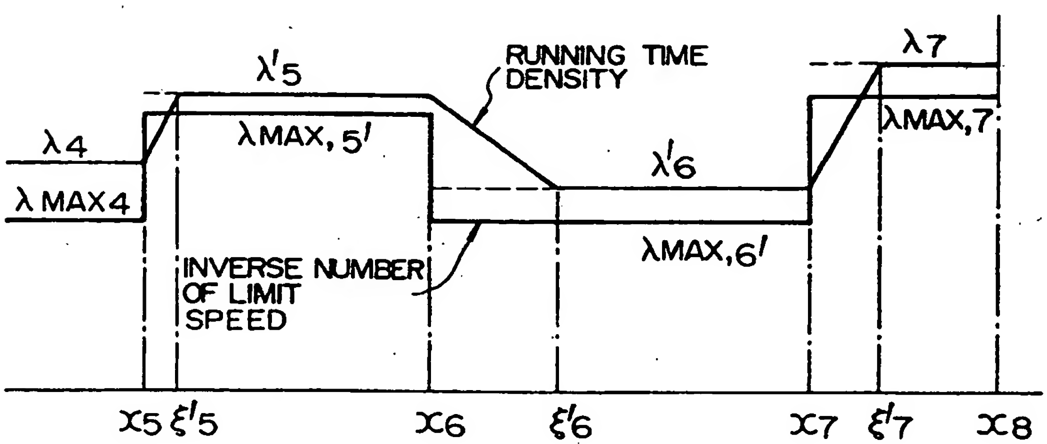

LIMIT SPEED
VMAX,4
VMAX, 6'
V4
RUNNING CURVE
V6'
VMAX. 5'
V5'
VMAX,7
V7
TERRITORY 4
TERRITORY 5
TERRITORY 6
TERRITORY 7
x5 ξ'5
x6
ξ'6
x7 ξ'7 x8

FIG. 21


λ7
λ'5
RUNNING TIME DENSITY
λ4
λMAX, 5'
λMAX,7
λ'6
λ MAX4
INVERSE NUMBER OF LIMIT SPEED
λMAX,6'
x5 ξ'5
x6
ξ'6
x7 ξ'7 x8